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John C. Caron

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THE EFFECT OF HIGH CONDENSING PRESSURES AND ULTRASONICS ON THE HARDNESS OF DENTAL AMALGAMS

A THESIS

Presented to

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by

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THE EFFECT OF HIGH CONDENSING PRESSURES AND ULTRASONICS

ON THE HARDNESS OF DENTAL AMALGAMS

Approved:

Chairman

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SUMMARY

The object of the present investigation was to study the variation between ultrasonically condensed and pressure condensed amalgams.

Compressive strength as a function of time was determined for varying condensing conditions. The strength was correlated with the growth of the Ag_2Hg_3 and Sn_8Hg phases determined from x-ray diffraction studies.

High condensing pressures produced stronger amalgams than those condensed by hand or ultrasonics because the mercury content of the amalgam was reduced. The high condensing pressures moved the particles closer together and reduced the amount of matrix. In these amalgams, condensed under high pressures, the cracks propagated through the alloy particles and the amalgams approached the strength of the alloy particle. The ultrasonically condensed amalgams were stronger than the hand condensed amalgams and reached their strength faster. Regardless of the condensing condition, the amalgams hardened by two different reaction rates. The first reaction rate was high and could be influenced by condensing methods, while the second rate was low and independent of the condensing method. Ultrasonic radiation produced the Ag_2Hg_3 phase more rapidly than any other condensing method. The Sn_8Hg phase appeared to be the mechanically stronger phase.

CHAPTER I

INTRODUCTION

In recent years much has been done to the alloys which go into the making of an amalgam filling. Time and money have been spent in research work by the American Dental Association, Bureau of Standards, manufacturers, and individuals to bring this universally used dental material to its present development (1).

The dental amalgam first came into focus in 1825 when M. Taveau began to use the formula of pure silver and mercury. It was called "Silver Paste." In 1834 it again appeared in an advertisement of the "notorious Crawcour brothers," who came to this country from England. They claimed to be its "inventors," calling it Royal Mineral Succedaneum. This decietful use of the amalgam so early in its history created a hostile attitude among the ethical members of the dental profession. From then on the amalgam as a filling material was destined to travel a troubled road for some years (1).

In 1844 the American Society of Dental Surgeons branded the use of the amalgam as malpractice. Historians of the time state that the fight over the use of the dental amalgam occupied the time of the American Society, almost to the exclusion of any other business, for several years. Even as late as 1920 there were persons who were still greatly prejudiced against the amalgam. Dr. Thomas P. Hinman, of Atlanta, said "We have all tried it, but amalgam is not stable. We may some day get a stable material but I question it as a general proposition, because I thoroughly believe that amalgam is a failure as a filling material." On the other hand, men of the highest standing were endorsing the use of the amalgam at this time. Thus, the amalgam had to overcome many prejudices to reach its stage of usefulness that it enjoys today.

The term "dental amalgam" today refers to the alloy silver-tin-mercury, which is the dentist's primary restorative material. The American Dental Association Specifications for Dental Amalgam Alloys are given in Table 1.

The dental amalgam is made by first weighing out specific ratios of the powdered silver-tin-alloy and mercury. These are then mixed in a mechanical amalgamator or a mortar and pestle. This mixing is called trituration. The trituration produces a plastic mass which the dentist immediately forces into a prepared tooth cavity. The amalgam then hardens in the cavity, restoring the tooth.

The forcing of the amalgam into the tooth cavity is called condensation. The condensing pressure used is known to affect the rate at which the amalgam increases in strength and its final strength. This is very important to the patient and dentist, since it appreciably determines how good the filling is going to be and the length of time the patient must refrain from eating solid foods. There are a number of physical properties of the amalgam which are important, but this research work will deal only with the compressive strength of the amalgam.

There has been considerable work over the years dealing with the effects of low condensing pressures on the final strength and rate of increase of strength of amalgams, but little work has been done on the effects

Table 1. Dental Amalgam Alloy Specifications

Metal	Composition (Wt. %)	Reason
Ag	65 minimum	Silver gives the amalgam high strength, rapid hardening and high expansion.
Sn	29 maximum	Tin reduces the expansion, causes slow setting and decreases the strength and hardness.
Cu	6 maximum	Copper replaces the silver and gives high expansion, hardens the amalgam, and gives the amalgam flow resistance.
Zn	2 maximum	Zinc combines with impurities thus protecting the other metals.
Hg	3 maximum	A percentage of mercury greater than this would make the final physical properties of the amalgam unpredictable.

of high condensing pressures on amalgams. This is probably due to the fact that the tooth itself is not compatible with excessively high pressures. It was found, however, that a high condensing pressure will yield an extremely high strength amalgam (2), and fracture occurred through the alloy particles rather than through the particle matrix alone.

Ultrasonic radiation in recent years has been found to produce better condensed amalgams with improved strength. It was the purpose of this study to determine the effects of high condensing pressures on the strength of amalgams and compare them with corresponding ultrasonic effects. The amalgams were hydraulically condensed in a breakdown die and then tested in a Riehle Universal testing machine at different time intervals for the compressive strength. A second set of samples was ultrasonically radiated by a transducer in the die for thirty seconds and the same testing procedure was followed to find the compressive strength. X-ray diffraction studies were made on the amalgams produced by these different condensing conditions and the phase growth was correlated with the strength-rate curves.

CHAPTER II

LITERATURE SURVEY

Phases

Ever since the amalgam was discovered in the 1800's, men have been trying to understand its strengthening mechanism. The first person to present any reliable information on the amalgam was Black (3) in 1895. In his works he discussed the composition, manufacturing, testing, and manipulation of the amalgam. McBain and Joyner (4) in 1912 proposed the first equation for the amalgam reaction.

$$Ag_3Sn + Hg \text{ (excess)} \rightarrow Ag_3Hg_4 + Sn \quad .$$

Further studies by Knight and Joyner (5), Gray (6), Gaylor (7), Troiano (8) and Stenbeck (9) showed that the reaction involved the phases of silver-mercury and tin-mercury. Table 2 on the following page gives the phases and their composition. By convention, subscript 1 refers to the silver-mercury phase, subscript 2 refers to the tin-mercury phase, and no subscript refers to the silver-tin phase. The phase diagrams for the above systems are given in Figures 1, 2, and 3.

Gaylor stated that the reaction formed β_1 and γ_2 first and then went to β_1 and γ_1 and γ_2. She proposed that the expansion of the amalgam was due to the β_1 and γ_1 phases and the contraction due to the free Sn plus Ag_3Sn.

Troiano stated, however, that γ_1 and δ_2 were first formed, going

Table 2. Composition of Amalgam Phases

Phase	
γ	25-27.5 Wt. % Sn-Balance Ag; Ag_3Sn
β_1	60 Hg-40 Ag Wt. % ; AgHg
γ_1	70 Hg-30 Ag Wt. % ; Ag_2Hg_3
δ_2	35 Hg Wt. %-Balance Sn (disputed)
γ_2	9-18 Hg Wt. %-Balance Sn
δ_1	Approximately 99 Hg Wt. %-Balance Ag

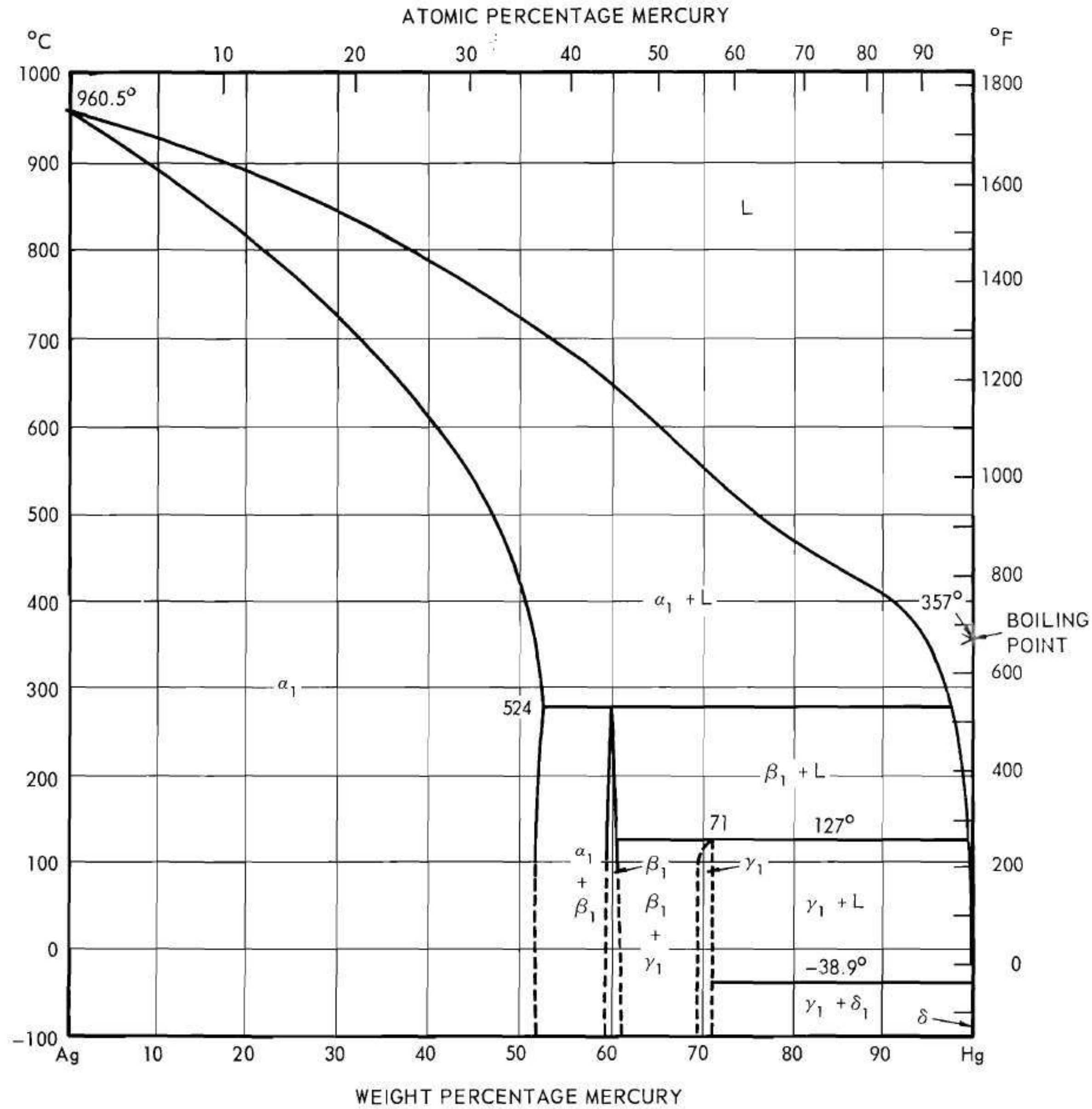

Figure 1. Silver-Mercury Phase Diagram (10).

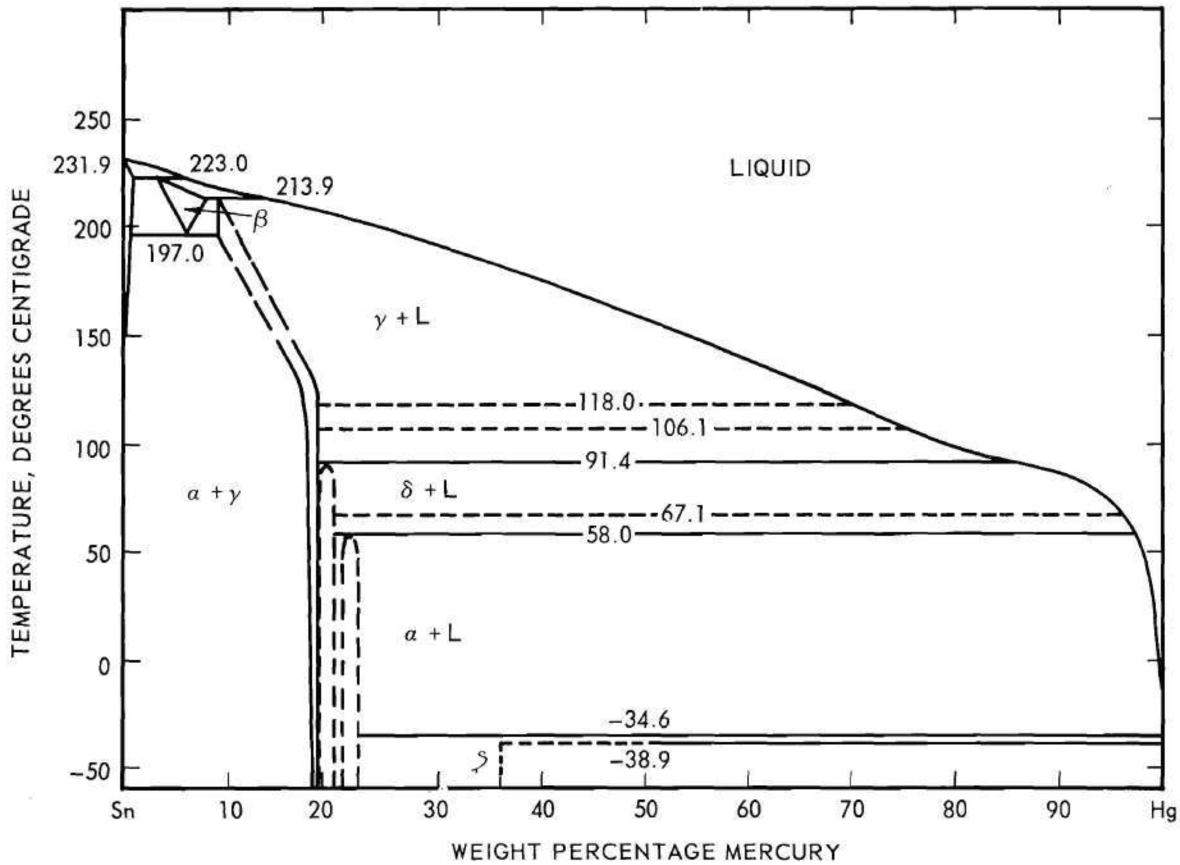

Figure 2. Tin-Mercury Phase Diagram (11).

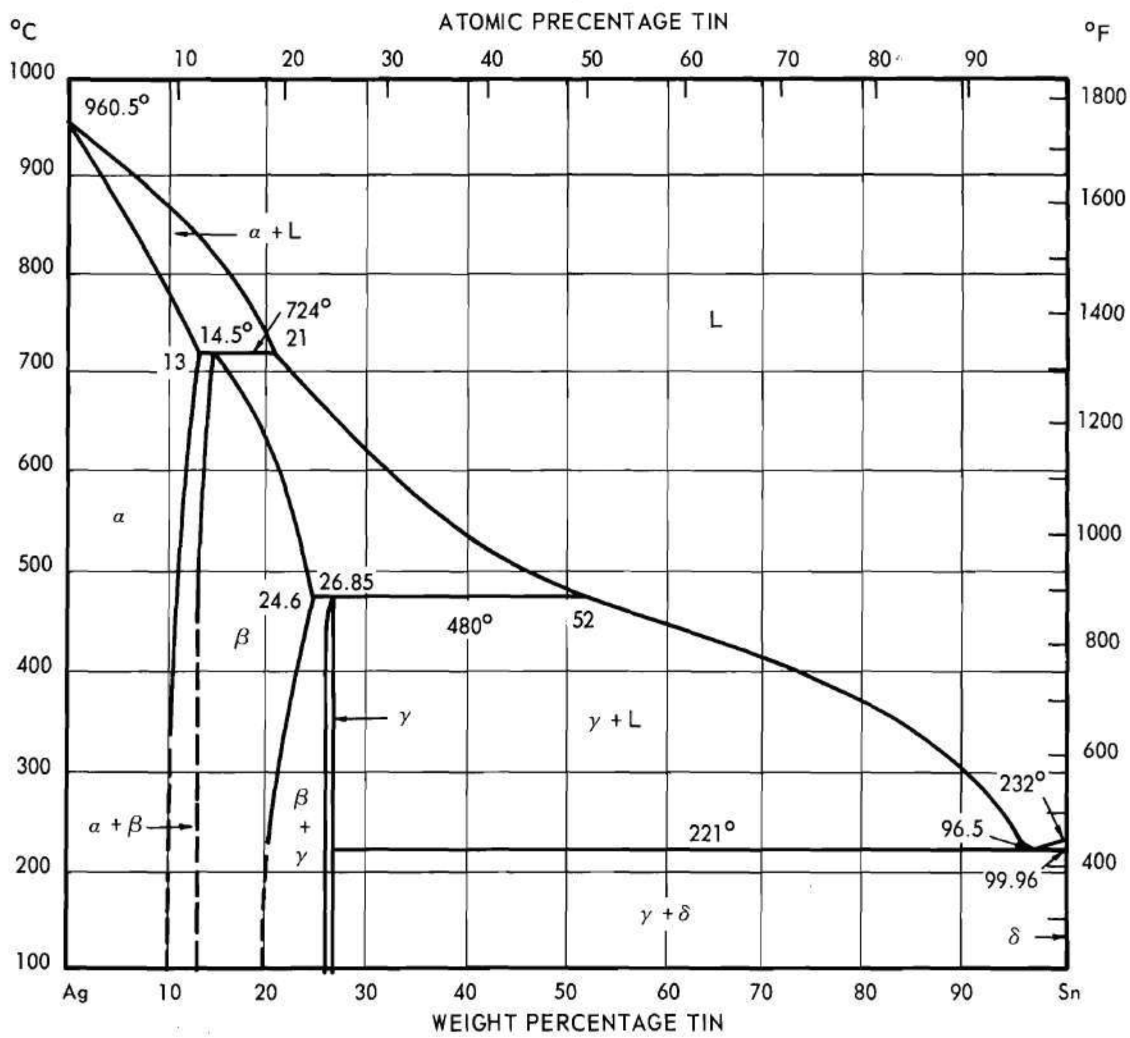

Figure 3. Silver-Tin Phase Diagram (12).

to γ_1 and γ_2, and then continuing on to $\gamma_1 + \gamma_2 + \beta_1$. He went on to say that expansion was due to dendritic growth and contraction due to the formation of the δ_2 phase in the γ_1 dendrites.

These theories have been extensively studied and criticized since their formation in the 1930's. Ryge (13), Fairhurst (14), Dreiner (15) and Wainwright (16) disagreed with the formation of the δ_2 phase.

A more recent theory that has been proposed is that the Ag_3Sn compound absorbs the Hg and two crystalline phases γ_1 and γ_2 appear. γ_1 forms first, but γ_2 grows faster. Ryge (17) gives the reaction as

$$Ag_3Sn + Sn + Hg \rightarrow Ag_2Hg_3 + (Sn, Hg) + Ag_3Sn \text{ (unreacted)} \quad .$$

Mitchell and co-workers (18) studied the phases present by freezing the amalgams. They found that when the liquid mercury vanishes the greatest dimensional changes take place. The initial shrinkage was attributed to the formation of phases having a small volume. The expansion was thought to be due to the unreacted mercury diffusing into the alloy particles and the later slight contraction again due to the formation of additional phases of a smaller volume than the starting material.

Koger (19) in 1965, using x-ray diffraction, found that the reaction of Hg with the silver-tin alloy is formulated as

$$Hg + \gamma \rightarrow \gamma_1 + \gamma_2 + \text{unreacted } \gamma$$

or

$$Hg + Ag_3Sn \rightarrow Ag_2Hg_3 + Sn_8Hg + Ag_3Sn(Hg) \quad .$$

The $Ag_3Sn(Hg)$ is a solid solution phase formed from the mercury diffusing into the Ag_3Sn particle. The Ag_3Sn then breaks down to form the silver and tin mercury phases. His work is the most conclusive in showing that the dental amalgam is made up of only the three phases, γ_1, γ_2, and unreacted γ. A δ_2 phase was not found either in the beginning or at the end of the reaction.

Factors Influencing Compressive Strength

The most important influencing factors are the manufacturing variables in alloy production, the size and shape of the alloy powder, the trituration process, the ratio of Hg to alloy, the temperature, and the condensation forces used. Of course the factors which affect the phases formed in the amalgam also influence its final strength, its rate of increase in strength, its flow characteristics and dimensional changes after setting. The strength of the amalgam can be measured by compressive, tensile, or transverse tests. Of these tests, only the compressive test is studied generally since it approximates mouth conditions.

In the manufacturing of the Ag_3Sn alloy, metals of relatively high purity are combined under conditions which will avoid oxidation and impurities. The powder is made by casting the alloy cylinder and then cutting it into fine particles with a lathe. Before cutting, the alloy must be heat treated at $425^{\circ}C$ for twenty-four hours to counteract the coring that took place when the alloy was cooled from the melt. The particles are cold-worked and will amalgamate rapidly. The resulting expansion is often undesirable. To avoid this, the fillings are aged for thirty minutes in boiling water. With these heat treated fillings, the amalgam has greater strength, less flow, a decreased tendency to expand, and a greater cohesiveness during condensation.

The size of the particle is very influential. A small particle size produces more rapid hardening of the amalgam with greater strength than larger alloy particles. Koger (19) has verified that these effects are due to the larger total reacting surface area of the small particles.

Shape is important. Spherical particle alloys were studied by Demaree and Taylor (20). They found that the advantages of the spherical alloys over the conventional alloys were: good control of physical properties by suitable blending of particle sizes, less sensitivity to manipulation variables, less flow, and higher early compressive strength.

The trituration effect was studied by Overberger, Povlich, and Sausen (21). Increased mechanical amalgamation caused a significant increase in the one-hour strength. However, excessive mechanical amalgamation then led to a decrease in strength. Taylor and co-workers (22) showed that no significant improvement in the crushing strength of amalgams resulted when mechanical rather than hand condensation was used.

Temperature is an important factor, not only because the amalgam has to harden in the mouth, but also due to the food's temperature causing mercury excretion from the amalgam. Petersen and Oaks (23) have shown that no significant difference appears in the compressive strength of amalgams hardened at room temperature and at mouth temperature.

Jorgensen and co-workers (24) found that the amalgam strength is essentially reduced by increasing temperature. Also, it was found that if the amalgam is heated and re-cooled the mechanical properties are regained after a short period of time.

One of the most influential factors on the strength of the amalgam is the condensing pressure. Phillips (23) in 1944 observed that the pneumatic condenser gave a slight increase in the crushing strength of the amalgam as opposed to those condensed by hand. Later Ryge and co-workers (26) found that two of the three methods of mechanical condensation used in their study resulted in a higher earlier and a higher final compressive strength than did hand condensation. Finally, Peyton and Liatukas (27) in 1961 observed that an amalgam of potentially high strength may show a loss of more than 10 per cent of its strength if poorly condensed. The above studies were performed at low condensing pressures. Phillips (28) in 1948 was the first to observe how the compressive strength varied with time at these low condensing pressures. The time interval ranged from one-half hour to six months. It was found that the amalgam, though quite weak during the first few hours, rapidly gained its strength and reached 85 per cent of its maximum strength at the end of the first eight hours. Jorgensen (29) also reports that with a time delay of five minutes in condensing the amalgam, there is a reduction in the compressive strength of 1.3 per cent of the maximum strength per minute of delay.

While studying the effects of these low condensation pressures on the compressive strength of the amalgam, a relationship between the residual mercury in the amalgam and the compressive strength was observed. Peyton and Liatukas (27) observed that a low mercury content in the amalgam was associated with high compressive strength values. Eames (30) showed that amalgams triturated with a 50:50 alloy to mercury ratio produced amalgams with early strength values which are higher than those usually expected. Taylor (31) in 1963 observed that residual mercury caused voids in the amalgam. Mahler and Mitchen (32) in 1964 showed conclusively that with decreasing residual mercury content in the amalgam the compressive strength increased correspondingly. Their results are shown in Figure 4 on the following page. Ward and Scott (2) in 1932, using extremely high condensing pressures, showed that the mercury content in the amalgam could be greatly reduced. They, however, studied dimensional changes of the amalgam with these high condensing pressures and only noted that an extremely high compressive strength was obtained. Their work connected with the mercury content is shown in Table 3.

Ultrasonics

Ultrasonics, over the years, has been used for many purposes such as cleaning parts, aiding industrial processes, forming and welding. Nosdreva (39) and Kapustin (40) showed that ultrasonics enhance crystallization, welding and machining. Nosdreva (39) also gave techniques for non-destructive testing with ultrasonics. Jones, Naropis, Thomas and Bancroft (41) presented studies relating to the development of ultrasonic welding equipment as well as weld strength and good metallurgical characteristics. Rhines (42) presented a rather complete picture of the microstructural changes occurring during the initiation and formation of an ultrasonic weld. Tarpley and Kartluke (43) have shown the beneficial effect of ultrasonics in hot pressing, and Rakovski (44) reported an increase in density and strength using ultrasonics in powder metallurgical problems. Langenecker (45,46,47) and his associate have shown the beneficial effects of ultrasonics on the deformation qualities of materials. Although this brief review indicated the potential of ultrasonic radiation, very little

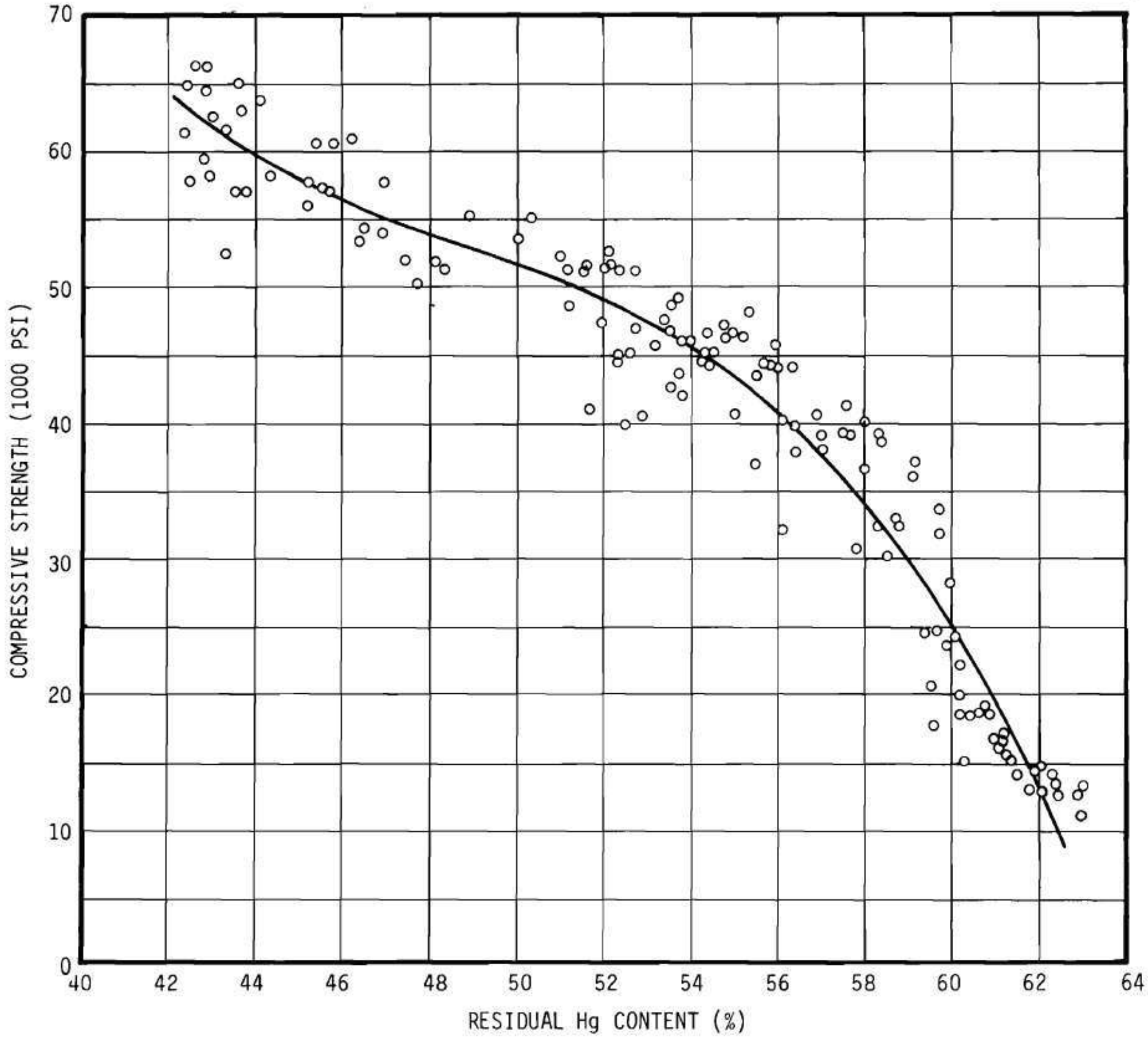

Figure 4. Relationship of Compressive Strength and Residual-Mercury Content of Amalgam.

Table 3. Variation of Mercury Content with Variation of Packing Pressure*

Lbs. Pressure Per Sq. In.		Percentage by Weight Hg
500	Tarred into specimen former	59.89
1,000	Very light hand pressure	54.48
2,000	Light hand pressure	53.01
4,000	Heavy hand pressure	47.47
8,000	Very heavy hand pressure	44.37
16,000		40.39
32,000		34.75
64,000		30.50
128,000		28.32
256,000		28.30

* Reference (2) Ward and Scott

work has been done in using it to condense dental amalgams.

The first to study the condensing of amalgams by ultrasonics with any success were Skinner and Mizera (33). They used an ultrasonic generator which delivered the energy to the handpiece with a frequency of 29,000 cps. They varied the relative output of their generator from 50 to 90 but had no measure of absolute energy. The alloy to mercury ratio was 5:8 and was mechanically triturated. The plastic mass was then squeezed as free of mercury as possible and placed under the condenser point. The condensation pressure was much less than that required by hand and intermittent application of pressure was found to be preferable to a continuous application. After one hour the ultrasonically condensed amalgams were found to have strengths greatly increased over those amalgams condensed by hand. The strength of both sets of amalgams after seven days was found to be about the same.

In 1964 L. E. Granath (34) used ultrasonic energy at 30,000 cps to condense amalgams. The alloy to mercury ratios were 5:5 and 5:7. The amalgam was mechanically triturated and condensed by ultrasonic vibration into cylindrically steel molds. Light hand pressure was used and the results obtained showed that the residual mercury in the amalgams was decreased.

Freiman (35) studied the effects of ultrasonics on the diffusion of mercury into the Ag_3Sn alloy. For this work a concave, water coupled transducer was focused on the Hg and Ag_3Sn alloy diffusion couple. The results of this work gave conclusive evidence that ultrasonic energy enhances the diffusion of Hg into the Ag_3Sn alloy.

Because it was seen from this survey that ultrasonics and high condensing pressures had the same effects on the residual mercury content of the amalgams, it was decided to investigate the strengthening effect of these two processes and compare them. A strength versus time relationship was first determined for the amalgams and then the curves were plotted. From these, comparisons between high condensing pressures and ultrasonics were made.

CHAPTER III

PROCEDURE

Materials

The alloy used in this study was of the commercial variety called "Optalloy" which is produced by the Caulk Company. The mercury used in this study was of the commercial variety available to the dentist on the open market.

Trituration

All the amalgams were prepared by weighing out the proportions of the alloy and mercury on a Dial-O-Gram balance which has an accuracy of a hundredth of a gram. This balance is the one shown in Figure 6. The alloy was weighed out on an onion skin paper and poured through a small plastic funnel into trituration capsules. The mercury was weighed in a glass beaker and poured into the capsule through the funnel. The capsule was then placed in a Wig-L-Bug vibrator and triturated for thirty seconds.

Hand Condensation

For the amalgams condensed by hand, the triturated amalgam was taken from the capsule and hand condensed in a 3/16-inch diameter tapered split die. This die is shown on the press in Figure 5. The amalgams were condensed with a 5/32-inch diameter condenser in four increments removing the excess mercury. A hand pressure of approximately 10.6 pounds was applied for one minute. The die was broken open and the 3/16-inch amalgam

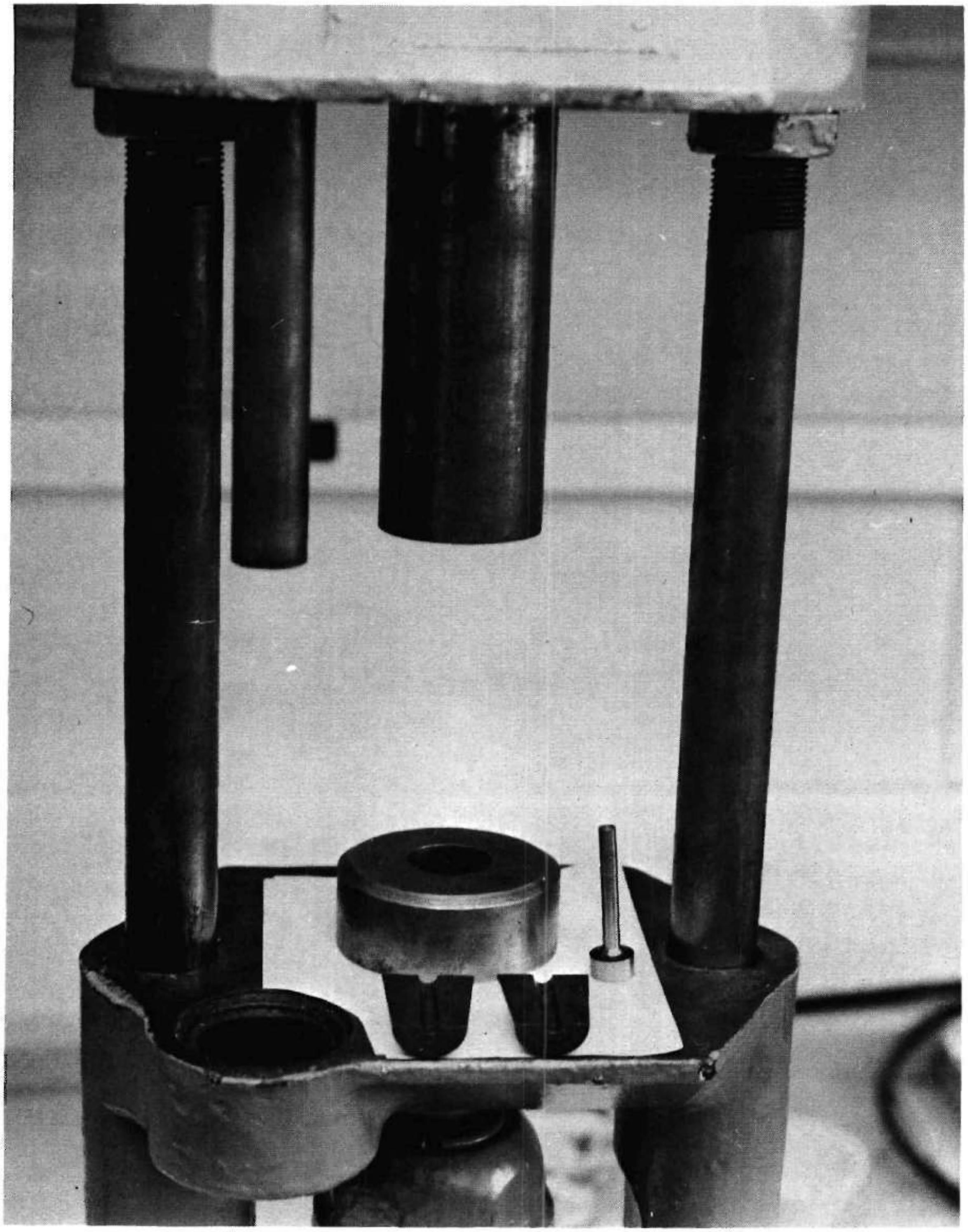

Figure 5. Hydraulic Press and Die.

pellet placed on the table to set. For the amalgams condensed with a .5 millimeter condenser, the increments were first condensed with the 5/32-inch condenser and then with the .5 mm condenser. This was done in three increments and took exactly five minutes. All times were recorded from the moment the die was broken open.

Mechanical Condensation

The amalgams condensed under a high condensing pressure were made by packing the amalgam loosely into the 3/16-inch diameter tapered split die. No mercury was expressed in the procedure. The condensed pressure was applied by a plunger using the hydraulic press shown in Figure 5. To carry out this operation the steel die was heat-treated to Rockwell C 60 to withstand the abrasion of the plunger, and the plunger was heat-treated to Rockwell C 52 to withstand these condensing pressures. The condensing pressure was applied for a certain prescribed time for the experiment and the pressure was read from a (0-10,000 psi) hydraulic pressure gauge attached to the press. This reading was then converted to the true condensing pressure. After the proposed time for condensing the amalgam, the die was broken open and time was recorded at this moment.

Ultrasonic Condensation

For the amalgam ultrasonically radiated, a piezoelectric transducer produced by Branson was used with an Automation Industries' power generator. To do these experiments the press was fitted with a head to hold the transducer, and the whole experimental apparatus is shown in Figure 6. The amalgam was loosely packed into the 3/16-inch diameter tapered split die and a stepped horn was designed from 99.99 per cent pure titanium to fit this die.

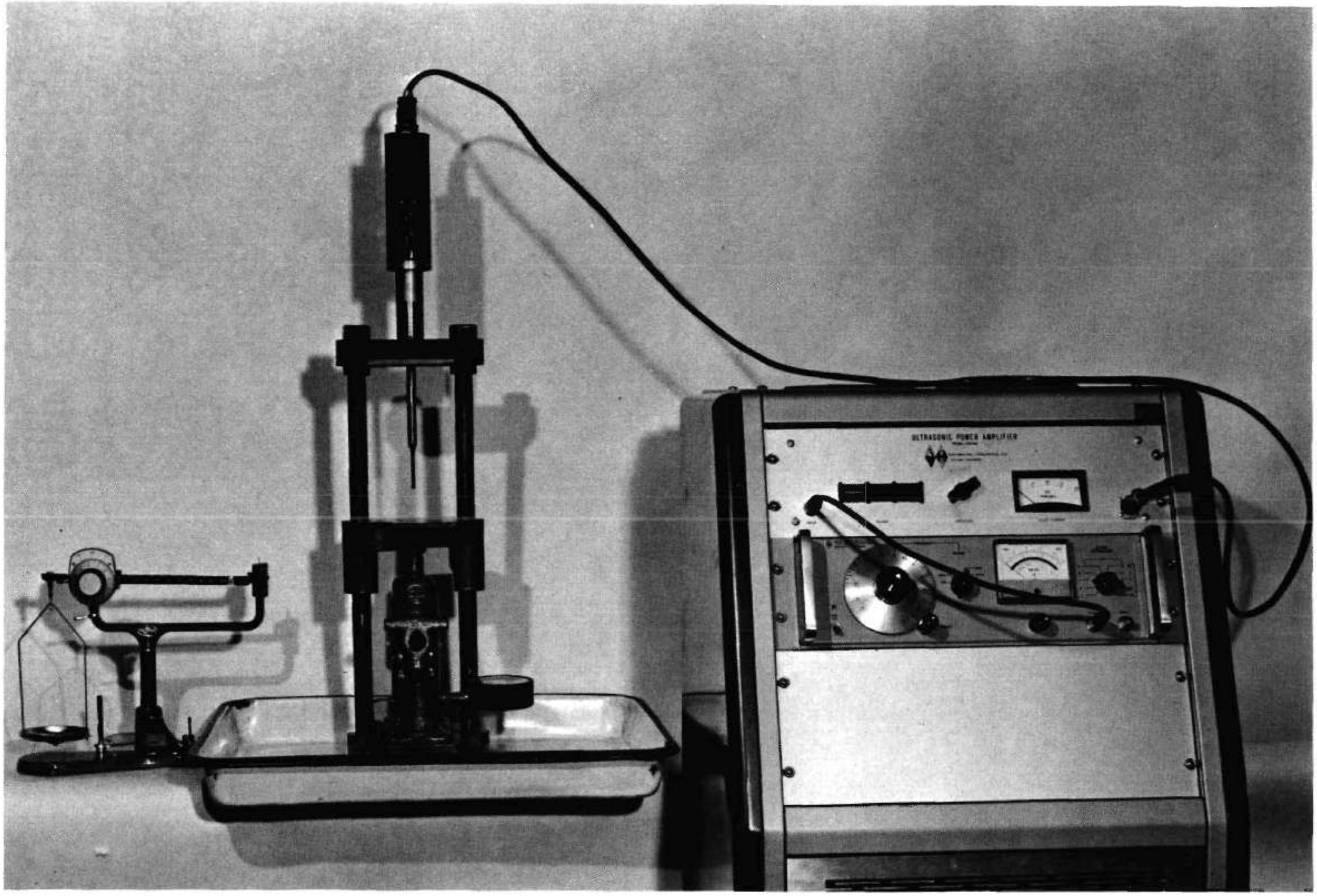

Figure 6. Ultrasonic Equipment and Weighing Scale.

The horn was stepped down from a 1/2-inch diameter to a 3/16-inch diameter using Fredrick's (36) curves for designing this type of horn.

An experimental Dow Chemical resin V2-246 was used as a coupling agent between the titanium horn and the horn attached to the Branson's transducer. For the amalgams radiated at a low amplitude, the frequency was set at 26,800 cycles per second and the horn lubricated with a light machine oil to protect against friction between the die and the horn. The amplitude meter was set at a reading of 3 in the middle scale and the amplitude knob was turned clockwise to 9 o'clock. This resulted in a plate current of .1 amp which corresponds to approximately 115 watts output from the power supply. The amalgam was radiated for 20 seconds at zero pressure. By zero pressure it is meant only enough pressure was used to keep the horn in contact with the amalgam in the die and this gave a zero reading on the gauge attached to the press. After the amalgam was treated, the die was broken open and the cylindrical pellet taken out. Time was recorded from this moment. To pack the amalgam loosely in the die and radiate it, required only two minutes from trituration. Amalgams condensed with high amplitude and no pressure were also performed. The amount of lubricating oil to perform this experiment,however, contaminated the amalgams. For the amalgams radiated at a high amplitude and pressure, the frequency was the same setting as that of the low amplitude. The amplitude meter setting for the high amplitude studies was the same as that for the low amplitude but the amplitude knob was turned clockwise to 12 o'clock. This gave a plate current of .2 amps which corresponds to approximately 210 watts. This setting was used for two seconds and for the next eight seconds the plate current dropped to .17 amps which corresponds approximately to 180 watts output from the power supply. The high amplitude amalgams were placed under a pressure of 9,800 psi while they were being radiated. The amalgams were then taken out of the die and time was recorded at this instance.

Density Measurements

The density measurements of the cylindrical amalgam pellets were made on an analytical balance. A thin wire was hung from the balance and weighed and then the wire was attached to a pellet and both were weighed together in air. A bridge was then placed across the balance pan and a beaker of water placed upon the bridge. The pellet and the wire were then weighed together in the water and then the pellet was dropped to the bottom of the beaker and the wire weighed alone in the water. The dropping of the pellet to the bottom of the beaker made sure that the wire was weighed at the same water level as when both the pellet and wire were weighed together. The room temperature was recorded and the density calculated.

Hardness Measurements

The Knoop hardness measurements of the amalgam were made on a Tukon microhardness tester. The amalgams to be tested were mounted in Quickmount, ground and polished. They were etched lightly with a 30 per cent nitric acid solution and Knoop hardness readings were made on the matrix and alloy particles in the amalgam.

Metallography Procedure

The metallographic samples were mounted in Quickmount and then ground on a wet belt sander. After this the samples were ground on water lubricated, SiC papers from 240 grit through 600 grit. A Buehler A. B. Microcloth was used with diamond paste for the polishing. The diamond paste ranged from 6 microns through .25 microns and methyl alcohol was used as the solvent. A less than a .1 micron Al_2O_3 was used for the final polish. The samples were then lightly etched with a 30 per cent nitric acid solution.

Mechanical Testing Procedure

To test the compressive strength of these 3/16-inch diameter cylindrical amalgam pellets, a Riehle Universal testing machine was used. A head speed of .05-inch per minute was used for these tests. It was decided to use this load rate because it more closely matched the load rates found in mastication as suggested by Mahler and Mitchen (32). Also, Caul and others (37) have found that this higher load rate yields a more constant compressive strength than the lower rates. It is believed that this was due to the fact that the rate was sufficiently high to eliminate the time dependent flow of the amalgam which causes lower strengths at lower load rates. Also, it was considered that a quicker testing time would yield a more realistic value of the compressive strength of the amalgam when it was being tested at a very early time. For the hand condensed and the ultrasonically radiated amalgams, the pellets' cylindrical ends were ground on polishing paper to produce an even, flat surface. The amalgam pellets compressed under high pressure did not require such extensive treatment due to the finish on these surfaces from the precision machined die and plunger. The time for the compressive strength was taken at the instant the amalgam pellet broke, and the highest strength was taken as the compressive strength.

Diffraction Work

X-ray diffraction studies were difficult because the specimen was in a cylindrical form. In order to get good results with a cylindrical sample, a spinner was designed to rotate the cylinder to get an integrated intensity for observing phase growth. While the sample was rotating, its cylindrical surface was kept parallel to the line beam and even to the plane of diffraction in the diffractometer. The sample and spinner were tilted correspondingly with the tilt of this diffraction plane in order to keep all geometrical relationships the same. This apparatus is shown in Figure 7. CuK_{∞} radiation at 35 KV and 30 Ma with a Ni filter was employed in conjunction with a proportional counter. One degree divergence and scatter slits were used with a 6 mil receiving slit. The diffractometer scanned between 29° 2θ and 41° 2θ with a scanning speed of 2° per minute. This range encompassed the peak of the Ag_2Hg_3 phase at 38° 2θ, the Sn_8Hg phase peak at 32.2° 2θ, and the $Ag_3Sn(Hg)$ phase peak at 39.6° 2θ. A Siemen's chart recorder was used to plot these results with a chart speed of 1-inch per minute.

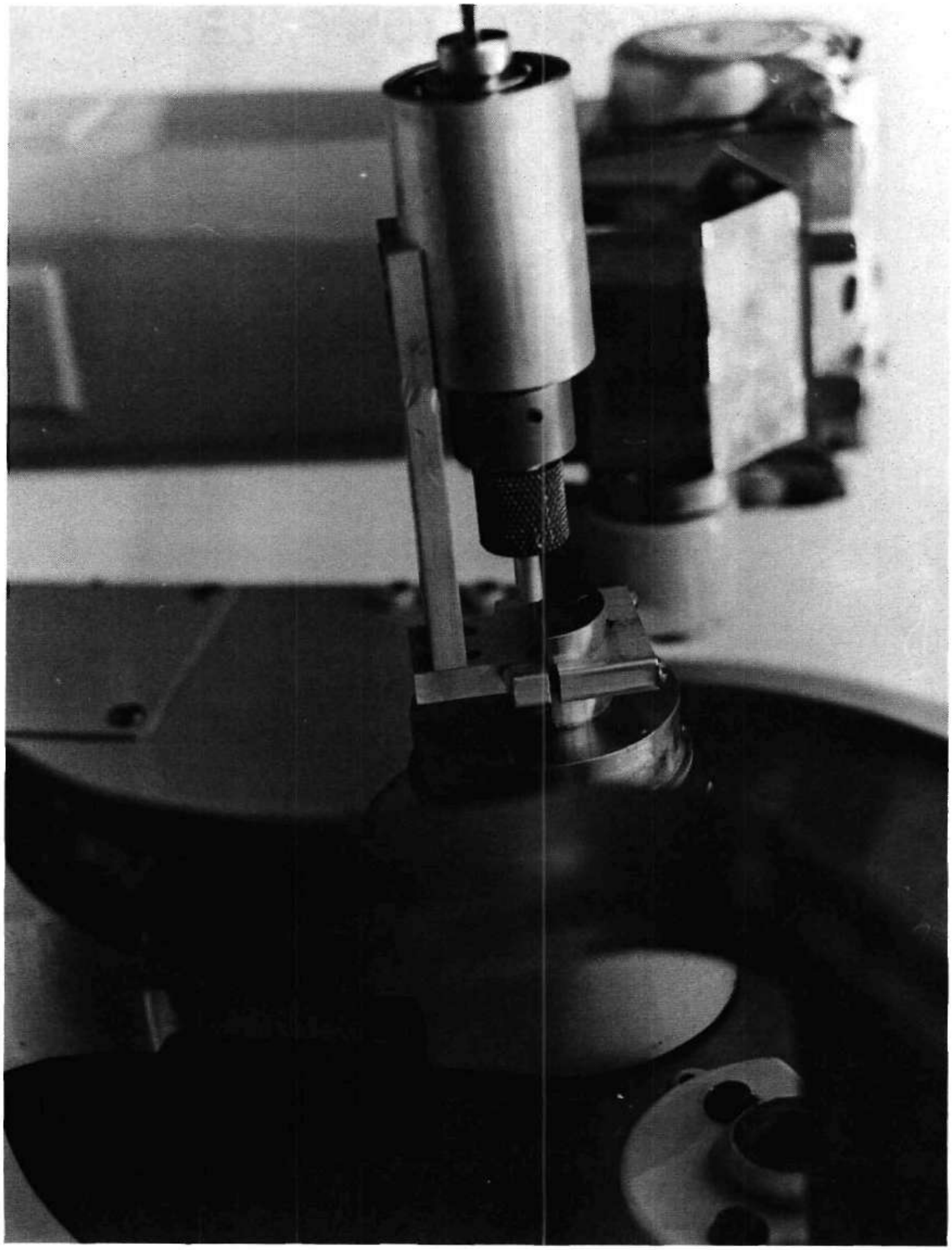

Figure 7. Cylindrical Rod Sample Spinner for X-ray Diffraction Studies.

CHAPTER IV

DISCUSSION OF RESULTS

Density Variation

The first data obtained on a mercury amalgam in this study was its density variation with different condensing pressures. Figure 8 shows that the density starts at approximately 10.95 gm/cm^3 and decreases to an asymtotic value of approximately 10.65 gm/cm^3. This decrease in density is not surprising, since mercury is expressed at condensation and the amalgam itself is a heterogenous mixture of both alloy particles and matrix. In Table 3 the results of Scott and Ward (2) show the effect of pressure on reducing the mercury content of the amalgam. Since there is less mercury present at these higher condensing pressures, less matrix of the silver-mercury and tin-mercury phases is formed. Thus, the density of the amalgam approached that of the alloy.

Microhardness Tests

In Figure 9 the Knoop hardness readings for the alloy particle are shown to increase from 20 ksi to 40 ksi, leveling off from 40 ksi to 60 ksi and then increasing again from there to a plateau at 98 ksi. This is interpreted to mean that as the condensing pressure increases the particles lose the cushioning effect of the matrix and start to support each other, since the particles were forced closer together by the high condensing pressures. The plateau level occurred at the point where the alloy particles were as near to each other as possible. The matrix shows a similar

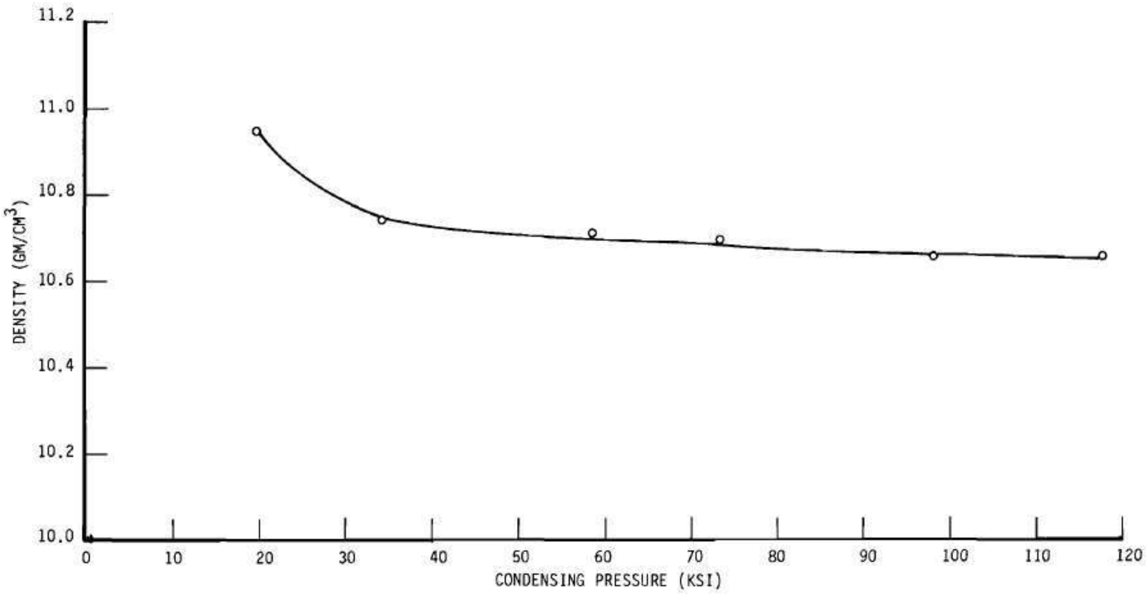

Figure 8. Density Versus Condensing Pressure for 48.3% Mercury Amalgam.

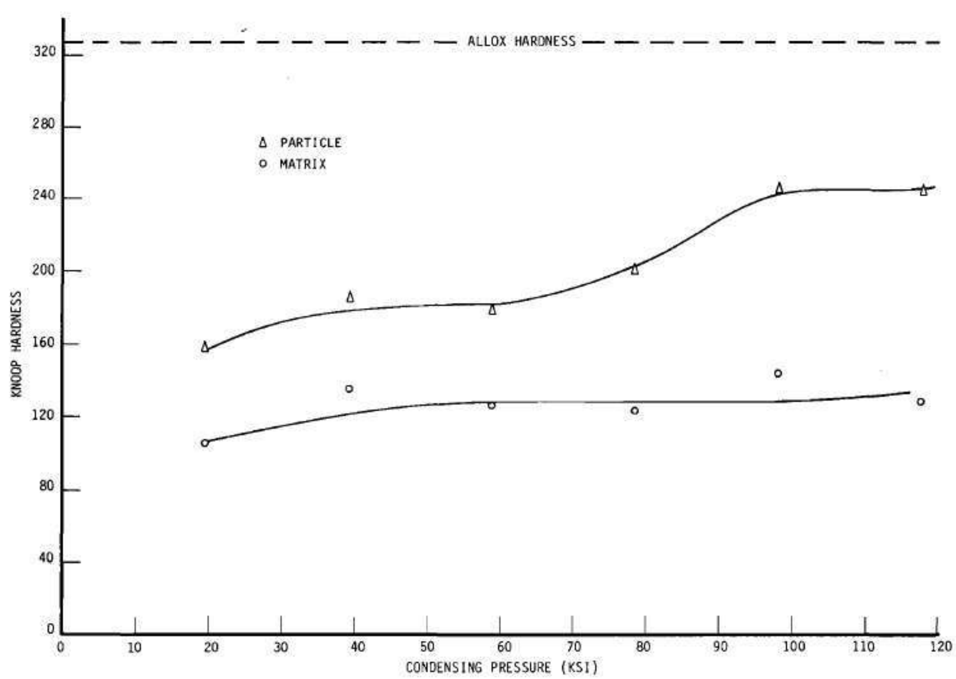

Figure 9. Knoop Hardness Versus Condensing Pressure for 48.3% Mercury Amalgam.

effect but to a lesser extent. It is noted also that the alloy particle is much harder than the matrix as was expected. No hardness readings were done on the 58.8 per cent mercury amalgam since Figure 8 shows that the initial mercury composition has only a very slight effect on the compressive strength in the 48.3 per cent mercury composition range.

Microstructure

Figure 10 shows vividly what happens to the amalgam with varying methods of condensation. In the etched samples the white areas are the alloy particles and the dark area the matrix. In the unetched samples, the white area is the amalgam and the dark areas are the voids.

From Figures 10a, d, f, and i, a decrease in voids with increasing condensing pressure is seen. The voids are thought to be caused not only by air gaps in the amalgam after condensation, but also due to residual mercury that has reacted to form a phase in the matrix. When the mercury diffuses and combines with other phases, a mercury void is left behind. This has been reported by Taylor (31), although he says the mechanism is not dependent upon the formation of particular product phases. Since it is known that the mercury content is reduced in an amalgam with increasing condensing pressure, it seems reasonable that the voids should also decrease with increasing condensing pressure. A more uniform structure results as shown from the microstructures. Figures 10b, e, g, and j show conclusively that the alloying particles are more closely packed with increasing condensing pressure, and that correspondingly the matrix is reduced. Also, Figure 10j shows that there is a slight tendency for the particles to align themselves. When the amalgam is held under a certain condensing pressure for

Figure 10. Microhardness Variation Due to Different Condensing Methods.

increasing lengths of time, the particles come closer together and align themselves perpendicular to the applied pressure. This is shown by Figures 10 l and p. Figures 10f, k, and o show that with increasing time under a certain condensing pressure, the voids are reduced slightly. Amalgams ultrasonically condensed in the study have microstructures similar to that of amalgams condensed mechanically with 9,800 psi. Correspondingly, their compressive strength versus time curves are similar.

The microstructures also reveal that the mode of fracture has changed with increasing condensing pressure. Whereas, under hand condensed pressures the cracks travel in the matrix between the particles, as reported by AsGar and Sutfin (38), the cracks now go through the alloy particles. This is shown in Figures 10h, mm, n and q. Figure 10c shows the crack traveling around the alloy particles in the matrix. The transgranular cracks have been observed in the amalgams compressed under pressures from 9,800 psi to 117,600 psi. These four pictures show vividly the transgranular cracking. With high condensing pressures, amalgam compressive strengths of 75,000 psi have been obtained. This is approaching the compressive strength of the alloy which is approximately 92,000 psi.

Compressive Strength

Compressive strength versus time curves were made to study the amalgam under various condensing conditions. The capital letter P, signifying property in general, in this work will represent the compressive strength of the amalgam. Results are shown in Figures B-1 through B-19 in Appendix B. From these curves, Figures 11 through 17 were drawn. These curves represent a plot of compressive strength (P) versus condensing pressure for a 58.8 per cent mercury amalgam for specific times. Three minutes after an amalgam is compressed, Figure 11 shows that there is a linear function between the compressive strength (P) and the condensing pressure applied to the amalgam. This would indicate that the early compressive strength of the amalgam is dependent upon the inter-particle spacing. Figure 12 which shows the compressive strength of the amalgams after a half hour from condensation indicates that there is no longer a linear relation between the compressive strength (P) and the condensing pressure. In Figure 13, which shows the one hour compressive strengths, there is a large difference between this curve and the curve for the half hour tests. The curve in Figure 13 indicates that above 40 to 50 ksi compressive strength, a change in reaction rate occurs. In Figures 14 through 17, which show compressive strengths for longer time intervals, the same general curve is shown. When the amalgams were tested at 37°C no significant change in compressive strength was observed. From the compressive strength versus time curves in Appendix B, Figure 18 was plotted to show the effect of the mercury composition on the compressive strength of the amalgam at a certain time and condensing pressure. This figure indicates that compositions from 50 per cent to 70 per cent mercury show very little effect on the compressive strength of the amalgam after 24 hours. For decreasing compositions below 50 per cent there is a corresponding decrease in the compressive strength. For a one-hour setting time there was an increase in strength with an increase in initial mercury. Figure 19 shows the effect of an amalgam put under a condensing pressure for a given time. This shows that there is only a slight increase in compressive strength with condensation time and that this could possibly be a linear function. Figures B-16,

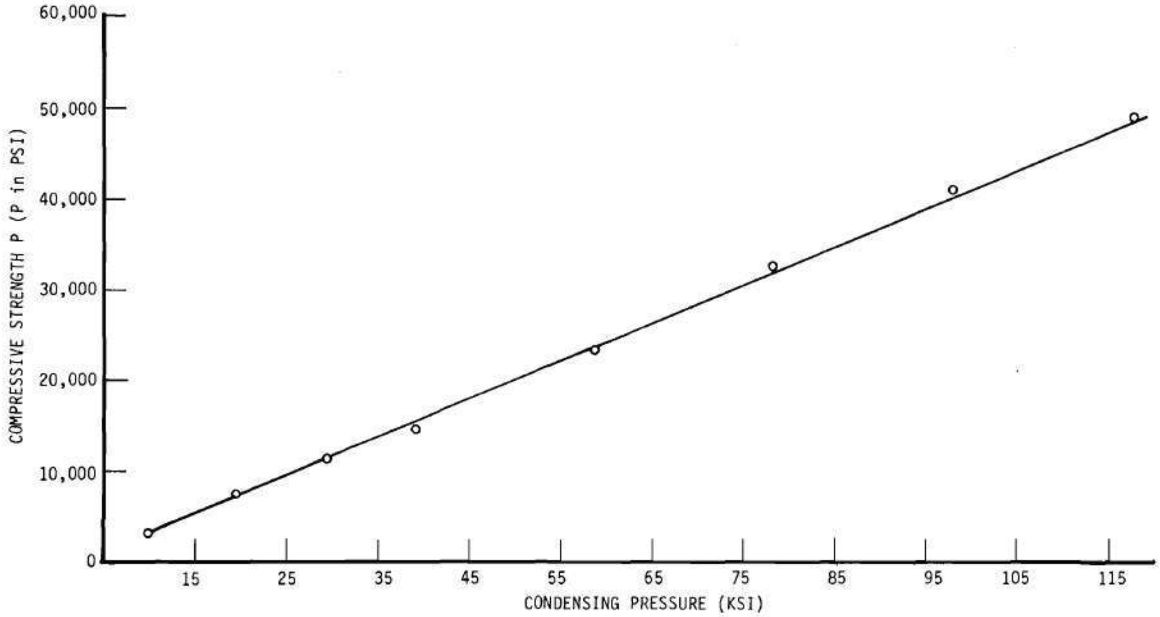

Figure 11. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 3 Minutes Out of the Die.

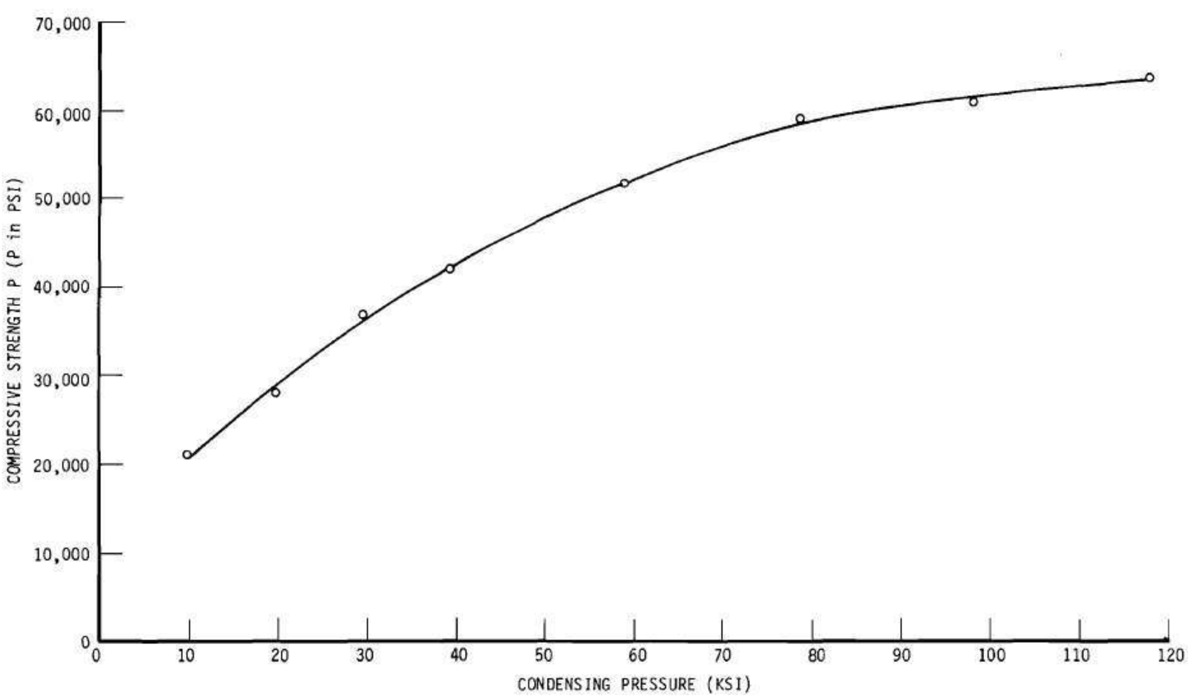

Figure 12. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 1/2-Hour Out of the Die.

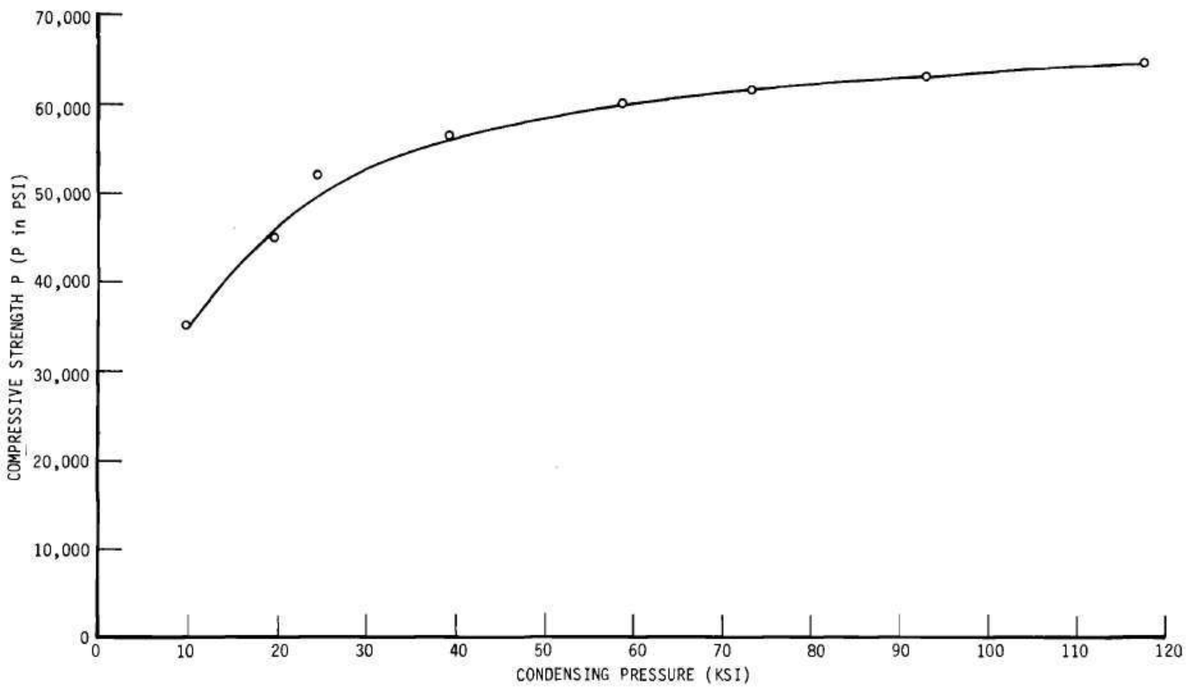

Figure 13. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 1 Hour Out of the Die.

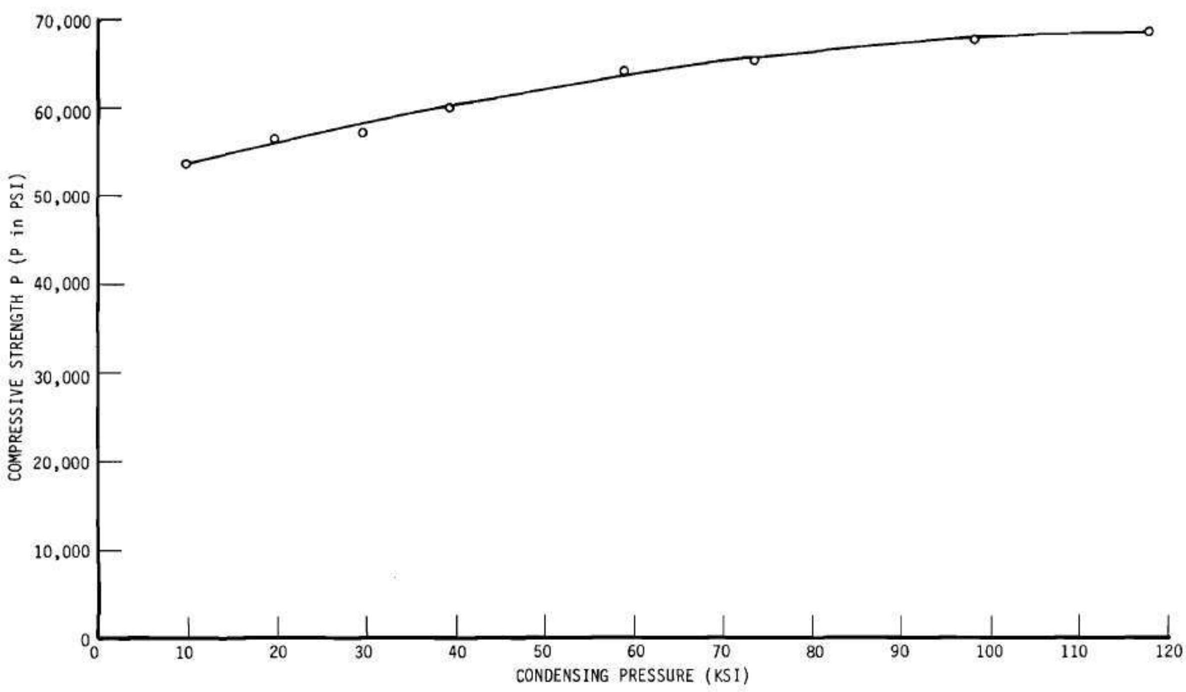

Figure 14. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 6 Hours Out of The Die.

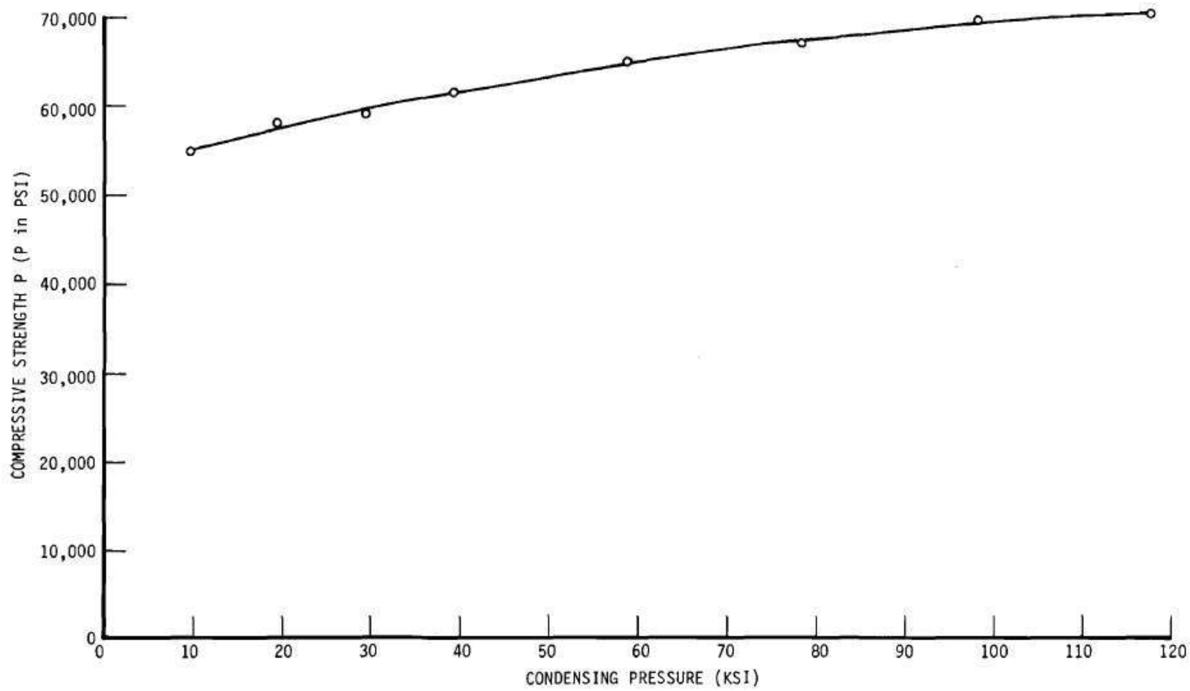

Figure 15. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 12 Hours Out of the Die.

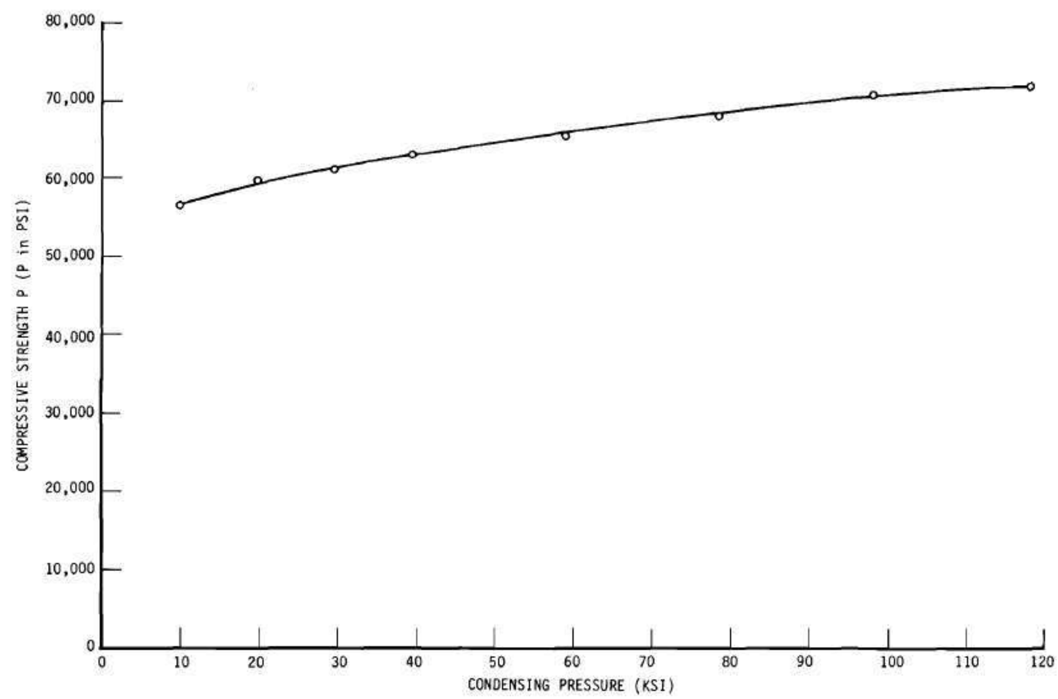

Figure 16. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 24 Hours Out of the Die.

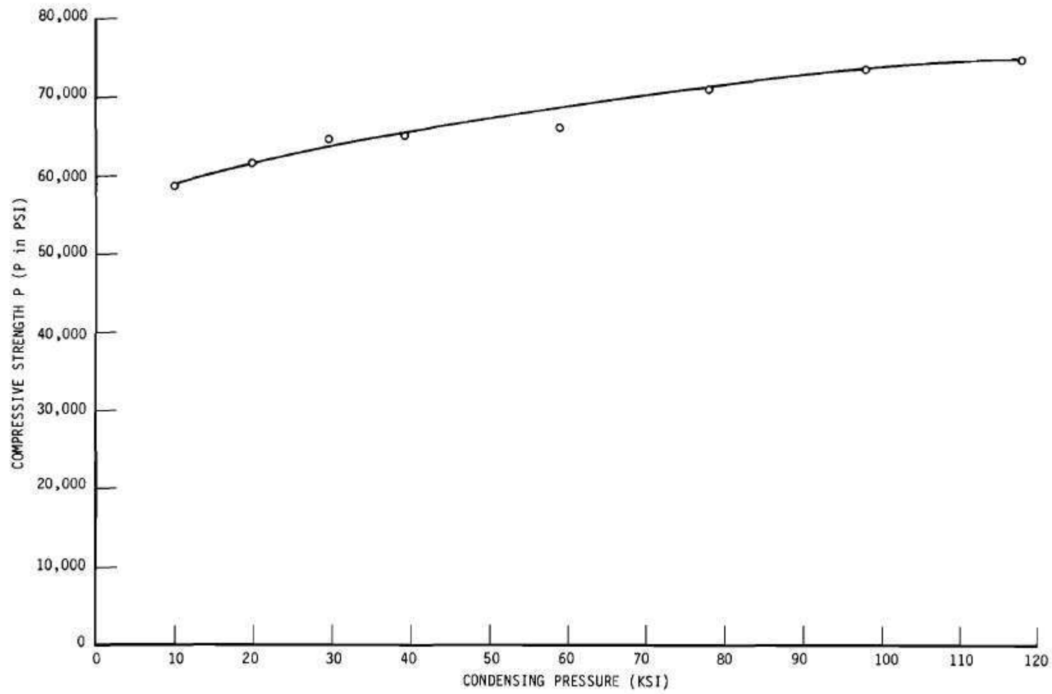

Figure 17. Compressive Strength Versus Condensing Pressure for 58.8% Mercury Amalgam, 72 Hours Out of the Die.

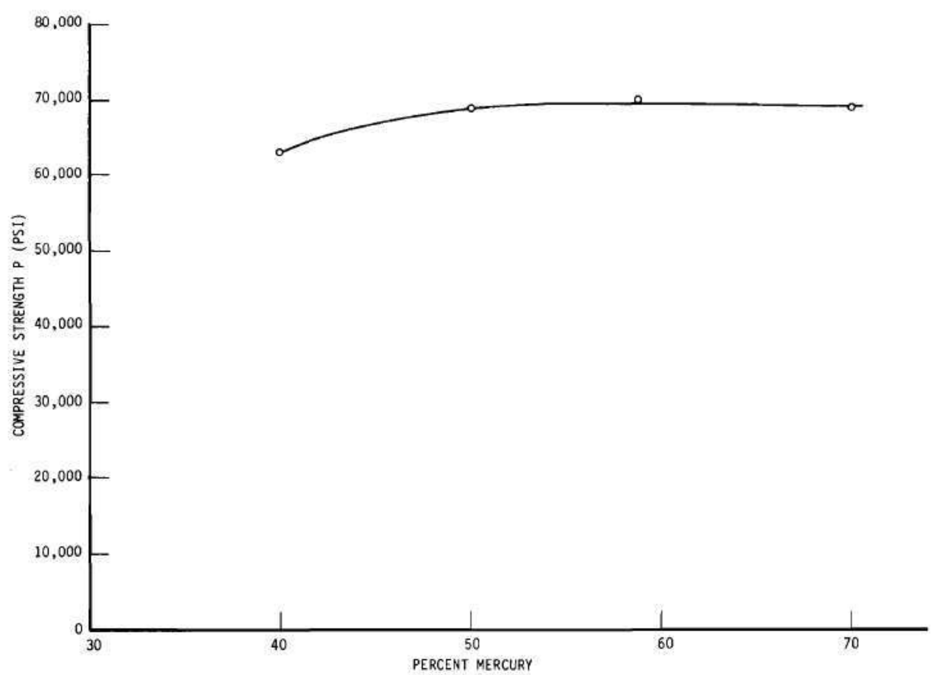

Figure 18. Compressive Strength Versus Mercury Composition for an Amalgam Condensed for 1 Minute at 86,200 psi.

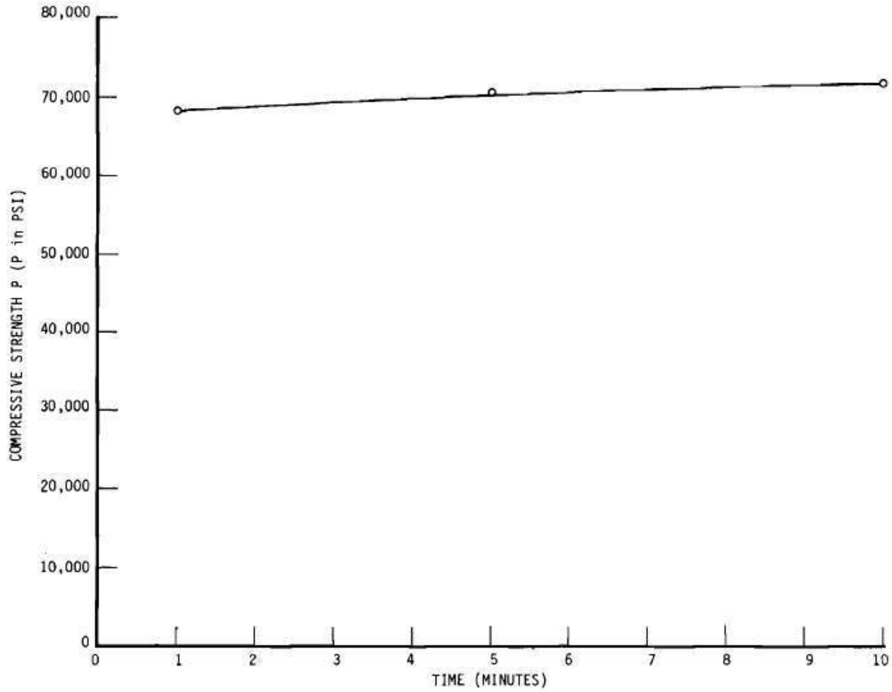

Figure 19. Compressive Strength Versus Condensing Time for 58.8% Mercury Amalgam Condensed at 78,400 psi.

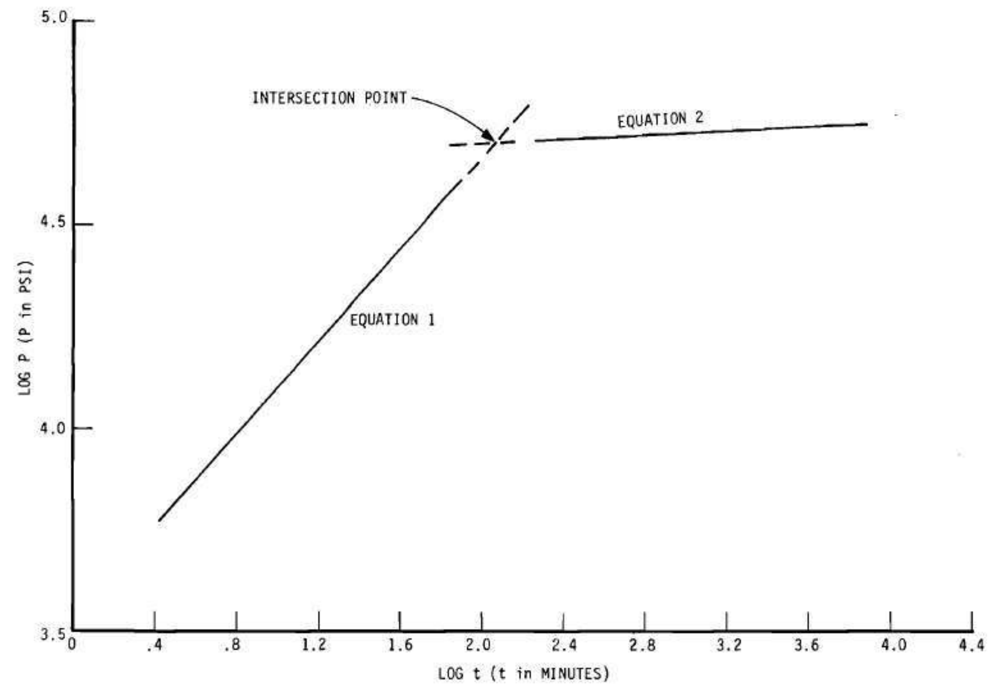

Figure 20. Schematic Graph for Log of the Compressive Strength Versus Log of the Time Out of Die for 58.8% Mercury Amalgam Under Various Condensing Conditions.

B-17, B-18, and B-19 in Appendix B, show that ultrasonic radiation caused a higher earlier compressive strength when compared with hand condensed amalgam behavior.

To check the reaction rates as the amalgam hardens with time, plots of Log P versus Log t were made. Typical results are shown in Figure 20. From these graphs, expressions were derived to correlate compressive strength with time. Table 4 gives a summary of the equations for the different condensing conditions. Looking at the exponents of t in Equation 1, it is obvious that, from 9,800 psi to 117,600 psi condensing pressure, the exponent is approximately .4. It is interesting to note that the exponent of t increases as the condensing pressure is increased from approximately 550 psi to 9,800 psi, and then the exponent slowly decreases back to the value it had as the condensing pressure increases to 58,800 psi. Also, from the Log P versus Log t plots in Appendix B, it can be seen that the first reaction rate changes in favor of the second reaction rate as condensing pressure increases. This leads one to conclude that a certain pressure between 550 psi and 9,800 psi is very favorable for reaction rate 1. The ultrasonic radiation has increased the time exponent to a value similar to that for amalgams condensed at 9,800 psi. Also, it is noticed that the ultrasonic radiation has more than doubled the exponent for the hand condensed amalgams. Reaction rate 1 is probably very diffusion-dependent since a time exponent of .5 is characteristic of a diffusion process. The time exponent for the second reaction rate shows no systematic variation, but a random statistical scatter. If these exponents are averaged for all condensation conditions, the value is 0.0315. Therefore, it seems reasonable that this second reaction rate cannot be

Table 4. Equation for the Compressive Strength of the Dental Amalgam Under Varying Condensation Conditions

Condensing Condition	Equation (1) (log equation) (antilog equation)	Equation (2) (log equation) (antilog equation)
58.8% Mercury Amalgam condensed under 9,800 psi for 1 Minute	$\text{Log } P = .8308 \text{ Log } t + 3.0791$ $P = 1200\ t^{.8308}$	$\text{Log } P = .0360 \text{ Log } t + 4.6386$ $P = 43{,}500\ t^{.0360}$
58.8% Mercury Amalgam condensed under 19,600 psi for 1 Minute	$\text{Log } P = .6245 \text{ Log } t + 3.541$ $P = 3{,}470\ t^{.6245}$	$\text{Log } P = .0338 \text{ Log } t + 4.662$ $P = 46{,}400\ t^{.0338}$
58.8% Mercury Amalgam condensed under 29,400 psi for 1 Minute	$\text{Log } P = .5408 \text{ Log } t + 3.7901$ $P = 6{,}150\ t^{.5408}$	$\text{Log } P = .0485 \text{ Log } t + 4.6343$ $P = 43{,}100\ t^{.0485}$
58.8% Mercury Amalgam condensed under 39,200 psi for 1 Minute	$\text{Log } P = .4686 \text{ Log } t + 3.9603$ $P = 9{,}120\ t^{.4686}$	$\text{Log } P = .0319 \text{ Log } t + 4.6977$ $P = 49{,}800\ t^{.0319}$
58.8% Mercury Amalgam condensed under 58,800 psi for 1 Minute	$\text{Log } P = .3643 \text{ Log } t + 4.1982$ $P = 15{,}800\ t^{.3643}$	$\text{Log } P = .0101 \text{ Log } t + 4.7824$ $P = 60{,}500\ t^{.0101}$
58.8% Mercury Amalgam condensed under 78,400 psi for 1 Minute		$\text{Log } P = .0317 \text{ Log } t + 4.7342$ $P = 54{,}300\ t^{.0317}$
58.8% Mercury Amalgam condensed under 98,000 psi for 1 Minute		$\text{Log } P = .0324 \text{ Log } t + 4.7482$ $P = 56{,}000\ t^{.0324}$
58.8% Mercury Amalgam condensed under 117,600 psi for 1 Minute		$\text{Log } P = .0329 \text{ Log } t + 4.7529$ $P = 56{,}600\ t^{.0329}$

Table 4. (Continued)

Condensing Condition	Equation (1) (log equation) (antilog equation)	Equation (2) (log equation) (antilog equation)
70% Mercury Amalgam condensed under 86,200 psi for 1 Minute		$\text{Log } P = .00169 \text{ Log } t + 4.8338$ $P = 68{,}200\ t^{.0017}$
58.8% Mercury Amalgam condensed under 86,200 psi for 1 Minute		$\text{Log } P = .0270 \text{ Log } t + 4.7630$ $P = 57{,}900\ t^{.027}$
50% Mercury Amalgam condensed under 86,200 psi for 1 Minute		$\text{Log } P = .0317 \text{ Log } t + 4.7385$ $P = 54{,}800\ t^{.0317}$
40% Mercury Amalgam condensed under 86,200 psi for 1 Minute		$\text{Log } P = .032 \text{ Log } t + .47017$ $P = 50{,}300\ t^{.032}$
58.8% Mercury Amalgam condensed under 78,400 psi for 5 Minutes		$\text{Log } P = .0307 \text{ Log } t + 4.7524$ $P = 56{,}500\ t^{.0307}$
58.8% Mercury Amalgam condensed under 78,400 psi for 10 Minutes		$\text{Log } P = .0314 \text{ Log } t + 4.7571$ $P = 57{,}100\ t^{.0314}$
58.8% Mercury Amalgam condensed under 78,400 psi for 1 Minute at 37°C		$\text{Log } P = .0419 \text{ Log } t + 4.7011$ $P = 50{,}300\ t^{.0419}$
58.8% Mercury Amalgam hand condensed (550 psi) for 1 Minute	$\text{Log } P = .4261 \text{ Log } t + 3.2864$ $P = 1{,}930\ t^{.4261}$	$\text{Log } P = .0349 \text{ Log } t + 4.5374$ $P = 34{,}400\ t^{.0349}$

Table 4. (Continued)

Condensing Condition	Equation (1) (log equation) (antilog equation)	Equation (2) (log equation) (antilog equation)
58.8% Mercury Amalgam hand condensed (34,000 psi) for 5 Minutes	$\text{Log } P = .4794 \text{ Log } t + 3.3544$ $P = 2{,}260\ t^{.4794}$	$\text{Log } P = .0260 \text{ Log } t + 4.6282$ $P = 42{,}500\ t^{.026}$
58.8% Mercury Amalgam ultrasonically condensed under a low amplitude at zero pressure for 20 seconds	$\text{Log } P = 1.028 \text{ Log } t + 2.4592$ $P = 288\ t^{1.028}$	$\text{Log } P = .0440 \text{ Log } t + 4.582$ $P = 38{,}200\ t^{.044}$
58.8% Mercury Amalgam ultrasonically condensed under a high amplitude at 9,800 psi for 10 seconds	$\text{Log } P = .8939 \text{ Log } t + 2.9091$ $P = 811\ t^{.8939}$	$\text{Log } P = .0391 \text{ Log } t + 4.6097$ $P = 40{,}600\ t^{.0391}$

greatly influenced by the condensing conditions.

Table 5 breaks the Log P versus Log t plots down to show the increase in strength with time for the various condensing conditions and also the length of time a patient should wait before masticating solid food. The intersection of Equations 1 and 2 gives the strength and time where the amalgam is safe from fracture by ordinary use. It is observed that with higher condensing pressures these intersection points reach a high compressive strength value in a shorter period of time. Ultrasonic condensation produced intersection points with higher compressive strength values than the hand condensed amalgams in a much shorter period of time. Amalgams condensed with a 0.5 mm condenser produced intersection points and strength curves slightly higher than hand condensed amalgams at 550 psi condensation pressure, even though at the 0.5 mm tip of the condenser there is a pressure of 34,000 psi. The 0.5 mm condenser produced only a slightly higher compressive strength for the reason that the amalgams flow around the tip of the condenser, whereas the amalgam cannot flow around the plunger in a die. It should also be pointed out that although the 5/32-inch diameter condenser gave only 550 psi from hand force, the condenser filled a fair portion of the 3/16-inch diameter die and not much amalgam could flow around it. This condenser gave compressive strength values within 7,000 psi of those specified by manufacturers for this alloy.

In general, it can be concluded that a higher condensing pressure gives a higher compressive strength. Ultrasonic radiation gives an earlier final strength even when no pressure is applied. An increase in trituration time and initial mercury content gives an increase in initial strength.

Table 5. Values of the Slopes of the Log P Versus Lot t Plots Plus Intersection Points, and Compressive Strength at Certain Times

			Intersection Point		Average Compressive Strength (psi)	
Condensing Pressure	Slope 1	Slope 2	Time (Min)	Pressure (psi)	2 Hrs (120 Mins)	72 Hrs (4320 Mins)
9,800	.8308	.0360	91.6	51,200	49,500	58,700
19,600	.6245	.0338	80.2	53,700	55,000	61,500
29,400	.5408	.0485	51.9	52,200	55,800	64,700
39,200	.4686	.0319	48.8	54,200	59,000	65,000
58,800	.3643	.0101	44.6	62,800	63,800	66,000
78,400		.0317			65,000	71,000
Hand Condensed						
5/32" dia. condenser (550 psi)	.4261	.0349	1578.0	44,600	16,000	46,000
.5 mm dia. condenser (34,000 psi)	.4794	.0260	644.0	50,300	20,000	53,000
Ultrasonically						
Low Amplitude (Zero Pressure)	1.0280	.0440	143.8	47,500	38,200	55,500
High Amplitude (9,800 psi)	.8548	.0391	97.5	48,700	48,300	56,400

Diffraction Studies

Figures 21 through 26 show the percentage of phases formed in the amalgam with respect to time. The highest intensity of the Ag_2Hg_3 phase peak at 38° 2θ was taken as I_∞ and relative percentages of the other data was calculated using this as 100 per cent. From these figures it is seen that ultrasonic radiation has decreased the time of forming 90 per cent of the Ag_2Hg_3 phase from ninety minutes for the hand condensed at 550 psi to nineteen minutes. The amalgams condensed under 9,800 psi form this portion of the phase in twenty-seven minutes, the amalgams under 39,200 psi in twenty-two minutes, and the 117,600 psi condensed amalgams in twenty-two minutes. It is also observed from these figures that the relative amount of the Sn_8Hg phase rises from 10 per cent to 50 per cent with increasing condensing pressure. This can be explained by the fact that the Sn_8Hg phase is completely formed first, and as mercury is expressed from the amalgam with higher condensing pressures, smaller and smaller amounts of the Ag_2Hg_3 phase form. The relative percentage of Sn_8Hg to Ag_2Hg_3 naturally rises correspondingly. This fact becomes very important when one looks at Figure 19 which shows the effect of ultrasonic radiation. Here the Sn_8Hg phase has a similar percentage as that for hand condensation (550 psi), but the Ag_2Hg_3 phase has been formed at an extremely rapid rate. Still the compressive strength has not increased to a very high value. With the higher condensing pressures, however, the relative percentage of Sn_8Hg phase increased along with an increase in compressive strength. Although with higher condensing pressures the cracks start traveling through the particles, this would still indicate that the Sn_8Hg phase is a mechanically stronger phase than the Ag_2Hg_3 phase. These figures would also indi-

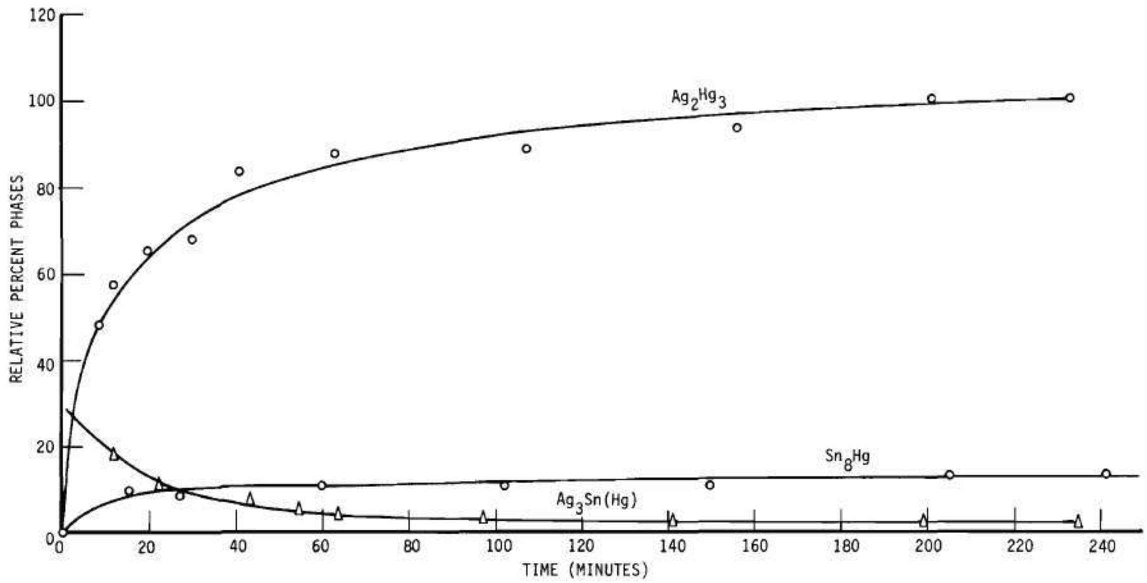

Figure 21. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Hand Condensed at 550 psi for 1 Minute.

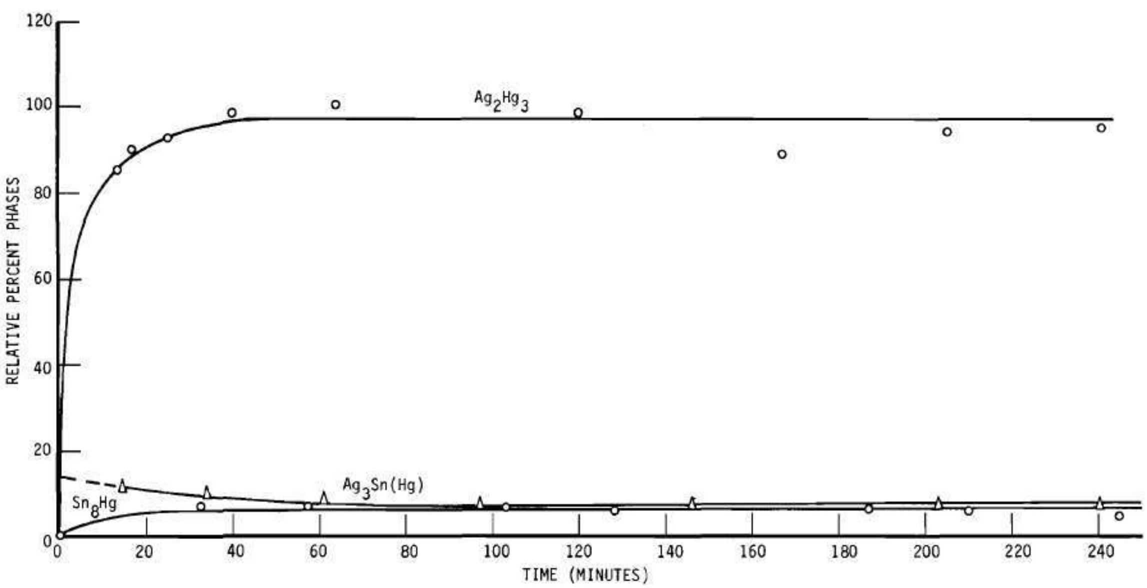

Figure 22. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Ultrasonically Condensed with a High Amplitude at 9,800 psi for 10 Seconds.

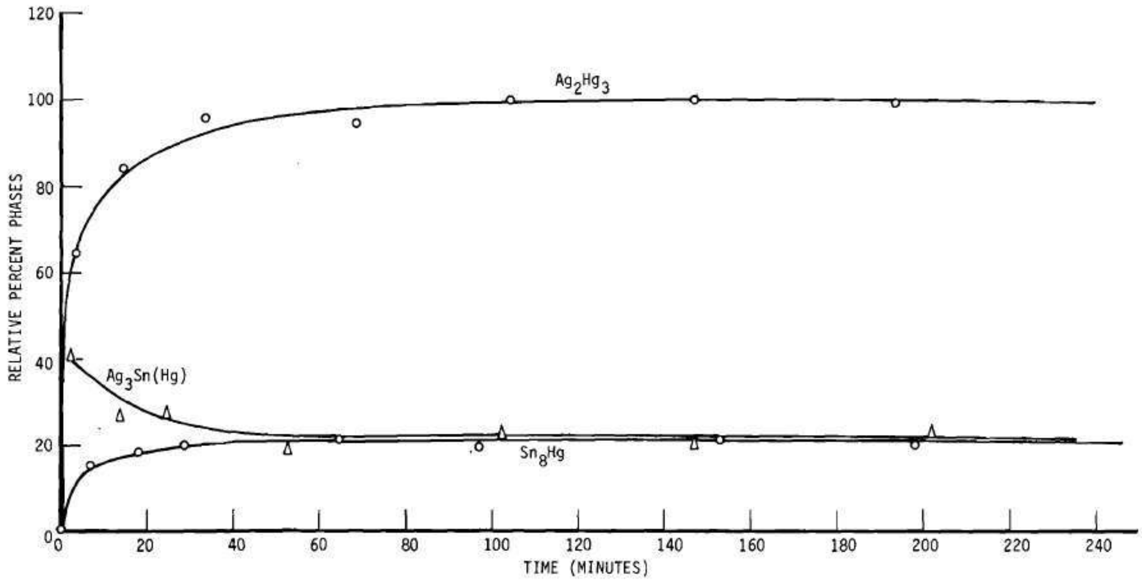

Figure 23. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Condensed at 9,800 psi for 1 Minute.

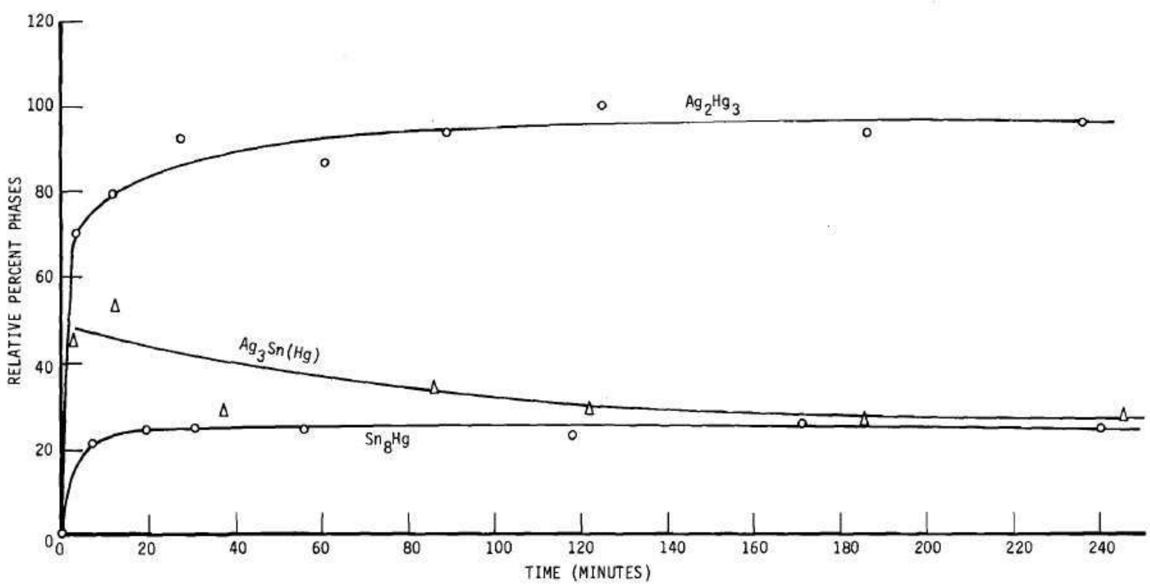

Figure 24. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Condensed at 19,600 psi for 1 Minute.

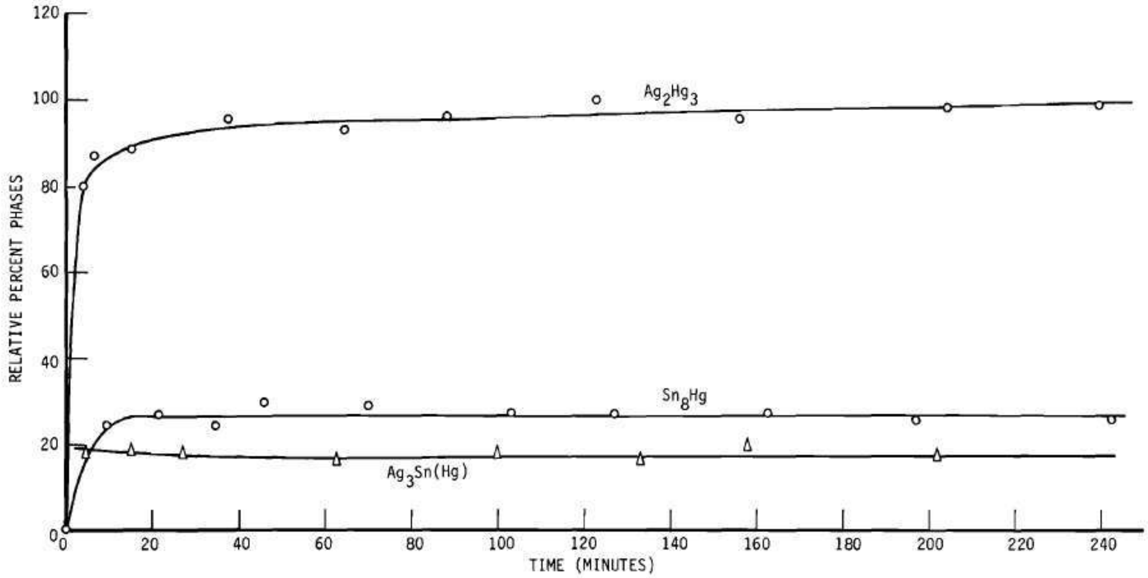

Figure 25. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Condensed at 39,200 psi for 1 Minute.

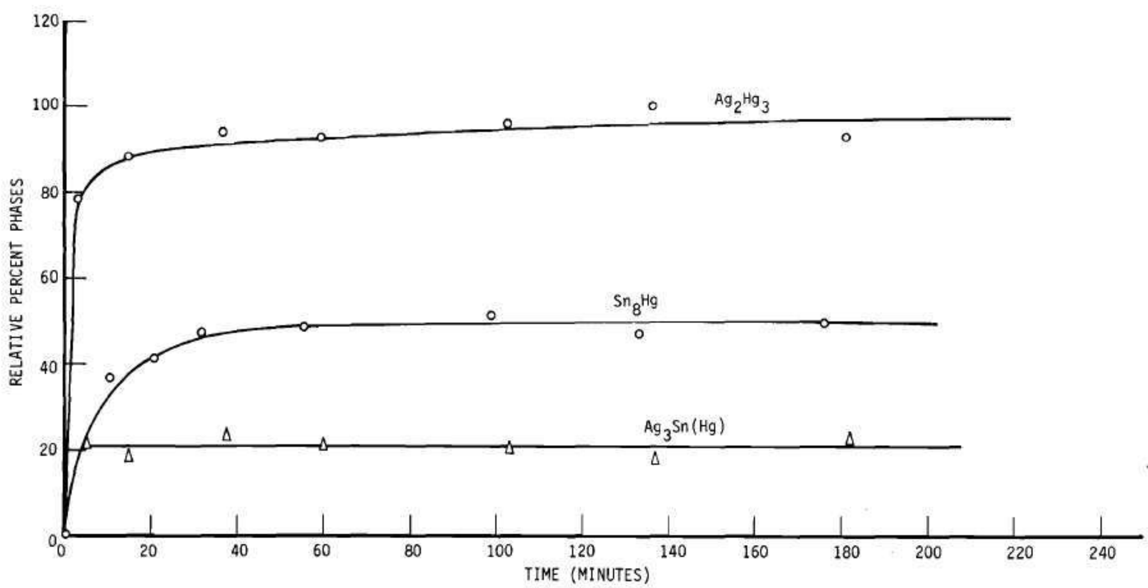

Figure 26. Relative Per Cent of Phases Versus Time for 58.8% Mercury Amalgam Condensed at 117,600 psi for 1 Minute.

cate that the silver-mercury and tin-mercury precipitates in the reaction rate 1 portion of the curve whereas the Ag_2Hg_3 is the more dominant precipitate in reaction rate 2. A systematic phase shift with time was observed for the ultrasonically condensed amalgams. However, the amount of shift was within the limits of error and more research work will have to be performed before any concrete conclusions can be determined.

Error Analysis

The amalgam shows statistical deviations because of its heterogeneous nature. To compensate for this in preparing the compressive strength time curves, usually four or more pellets were prepared for each point and the strength results averaged. The times were also averaged. Usually the error was kept in a range of $\pm$ 5 per cent. This worked very well for the part 2 of the reaction rate curve, but in the early stages the variance was more difficult to control. To compensate for this, the points were examined relative to their position with each other, and where some seemed out of position, more pellets were prepared for that point. All variances are shown on the compressive strength versus time curves. All numbers containing decimals are good to the third place and approximate to $\pm$ 5 in the fourth place. High numbers were rounded off to the third digit.

The x-ray data precision is also within $\pm$ 5 per cent. The x-ray data error is a little larger than usual since the integrated intensity was determined from a paper weighing technique which contained "human error."

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. High condensation pressures produce stronger amalgams than hand or ultrasonically condensed amalgams by reducing the mercury content in the amalgam. This moves the particles closer together and reduces the amount of matrix.

2. The strength of the high pressure condensed amalgams approaches the strength of the alloy particle with fracture occurring in the high pressure condensed amalgams by cracks traveling through the particles.

3. The ultrasonically condensed amalgams are stronger and reach their strength faster than the hand condensed amalgams.

4. Amalgams harden first at a high reaction rate and then harden at a low reaction rate, with the higher rate being dependent on the condensation process.

5. The Sn_8Hg phase appears mechanically stronger than the Ag_2Hg_3 phase.

Recommendations for Further Research

1. This work should be done with spherical particles since a greater condensing effect is obtained with spherical alloys.

2. The effects of ultrasonics should be studied at varying frequencies as well as higher amplitudes to see if a shorter wave length approaching the size of the particle will produce great condensing effects.

3. More research on the two reaction rates and the mechanisms examined to explain exactly how the phases are hardening the amalgam.

4. Ultrasonic energy applied to drier mixes which have a faster setting time should be studied to determine how effectively ultrasonic implements can carve this amalgam.

5. Peak shifts studies of ultrasonically condensed amalgams should be performed to determine the behavior of mercury in the amalgams.

APPENDIX A

SAMPLE CALCULATIONS

APPENDIX A

SAMPLE CALCULATIONS

Density

Weight wire in air - .0505 gm. Weight wire + pellet in air - 2.6322 gm.

Weight wire in water - .0494 gm. Weight wire + pellet in water - 2.3888 gm.

$$\begin{array}{r} 2.6322 \text{ gm.} \\ -\ .0505 \text{ gm.} \\ \hline 2.5817 \text{ gm.} \end{array} \text{ weight pellet in air} \qquad \begin{array}{r} 2.3888 \text{ gm.} \\ -\ .0495 \text{ gm.} \\ \hline 2.3393 \text{ gm.} \end{array} \text{ weight pellet in water}$$

$$\begin{array}{r} 2.5817 \text{ gm.} \\ -2.3393 \text{ gm.} \\ \hline 0.2424 \text{ gm.} \end{array} \text{ weight of displaced water}$$

At 23°C density water = 0.9972 gm/cm^3.

$$\text{Volume of pellet} = \frac{.2424 \text{ gm.}}{0.997 \text{ gm/cm}^3} = .24308 \text{ cm}^3$$

$$\text{Density of pellet} = \frac{2.5817 \text{ gm.}}{.24308 \text{ cm}^3} = 10.6207 \text{ gm/cm}^3$$

Area of Pellet

Diameter = 3/16"

Radius = 3/16" x 1/2 = 3/32"

$$A = \pi R^2 = \pi\ (3/32)^2 = \pi\ (.0087891)$$

$$A = .027597 \text{ in}^2 = 2.7597 \times 10^{-2} \ .$$

Condensing Pressure

Mechanical -

Force on press cylinder = Force on pellet

(Reading from psi dial on press) (Area of press cylinder) = (Area of pellet) (pressure on pellet).

Example:

Dial reading - 1000 psi

Area of press cylinder - 1.08 in ^{2}

Area of pellet - 2.7597×10^{-2}

(1000 psi) (1.08 in ^{2}) = (2.7597×10^{-2}) (pressure on pellet)

$$\text{pressure on pellet or condensing pressure} = \frac{1 \times 10^3 \times 1.08}{2.7597 \times 10^{-2}} = 39{,}200 \text{ psi (rounded off to third digit)}$$

Hand - The force applied by hand to the condensed varied around 10.6 pounds, usually to a smaller value.

Area of 5/32-inch diameter condenser = π (.006103) = .01915 in ^{2}

$R = 5/32\text{-inch} \times 1/2 = 5/64\text{-inch radius}$

$A = \pi\ (5/64)^2 = \pi\ (.07812)^2 + \pi\ (.006103) = .01915 \text{ in}^2$

$$\text{Condensing pressure} = \frac{10.6\#}{1.915 \times 10^{-2}} = 553 \text{ psi}$$

550 was decided to be used to represent hand condensing with this condsner.

Area of .5 mm condenser = πR^2

.5 mm = .05 cm $\qquad \dfrac{.05 \text{ cm}}{2.54 \text{ cm/in}} = .01968$ inches

Radius of condenser = .01968 inches x 1/2 = .00984

$A = \pi\ (.00984")^2 = .000304 \text{ in}^2$

condensing pressure $\frac{10.6\#}{3.04 \times 10^{-4}} = 34{,}868$ psi.

34,000 psi was decided to be used to repressnt hand condensing with this condenser.

Equations

For the Log P, Log t plots, a straight line relationship exists for the data. Thus, an equation for a straight line can be used to represent this relationship.

Let P = Compressive Strength (psi)

t = Time (min)

C_1 = (slope of straight line in Log P, Log t plots)

K = intercept of straight line in log pressure Log t plots

C_2 = antilog of K

$$\text{Log } P = C_1 \text{ Log } t + K \tag{1}$$

$$K = \text{Log } C_2$$

regrouping,

$$\text{Log } P = \text{Log } t^{C_1} + \text{Log } C_2$$

$$\text{Log } P = \text{Log } C_2 \, t^{C_1}$$

$$P = C_2 \, t^{C_1} \tag{2}$$

To determine the slope C_1 and the intercept K of the Log equation the least squares approximation for a straight line was used:

$$MK + C_1 \left[\sum_{i=1}^{M} (\text{Log } t)i \right] = \sum_{i=1}^{M} (\text{Log } P)i \quad . \tag{3}$$

$$\left[\sum_{i=1}^{M} (\text{Log } t)i \right] K + \left\{ \sum_{i=1}^{M} [(\text{Log } t)i]^2 \right\} C_1 = \sum_{i=1}^{M} (\text{Log } t)i \, (\text{Log } P)i \quad . \tag{4}$$

M = number of data points.

The two equations were then solved simultaneously for C_1 and K.

Deriviation

An expression describing the rate of change of compressive strength with respect to time and the compressive strength at that time can be derived as follows:

Let

P = Compressive Strength
t = Time
K = Constant
C_1 = Constant

$$\text{Log } P = C_1 \ \text{Log } t + K$$

differentiating

$$\frac{d \text{ Log } P}{d\ t} = C_1 \ d \frac{\text{Log } t}{d\ t} + 0$$

with respect to time

$$d \text{ Log } P = C_1 \frac{d \text{ Log } t \; d \, t}{d \, t}$$

$$\frac{d \text{ Log } P}{d \text{ Log } t} = C_1 \quad ,$$

rewriting d Log P and d Log t,

$$\frac{dP}{P} \cdot \frac{t}{dt} = C_1$$

$$\frac{dP}{dt} = \frac{C_1 P}{t} \quad . \tag{5}$$

Equation (5) shows that the rate of change of the compressive strength is directly proportional to the compressive strength at that instant and inversely proportional to time at that instant. In other words, the rate of change of the compressive strength decreases with time and increases with strength. This equation provides the means for determining the amalgam's strength rate at certain times from strength versus time curves. This should encourage activation energy studies.

APPENDIX B

EXPERIMENTAL RESULTS

Table B-1. Raw Data for the 58.8% Mercury Amalgam Condensed Under 9,800 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:04		3,261	
:03	:037	3,805	3,442
:03		3,261	
:16		11,958	
:17		14,313	13,090
:15	:163	12,864	
:17		13,226	
:36		20,836	
:30		20,292	21,108
:30	:315	23,010	
:30		20,292	
:47		28,989	
:46	:458	29,170	
:46		32,250	28,853
:44		25,003	
1:12		37,504	
1:02		34,786	
:54	1:01	31,525	35,149
:48		26,271	
1:11		43,664	
1:05		36,417	
:57		35,874	
2:45		54,173	
2:38		52,361	
2:31	2:32	53,629	52,950
2:15		51,636	
8:58		54,354	
8:49	8:37	55,411	54,807
8:26		53,267	
8:15		56,166	
15:26		54,716	
15:18	15:14	55,260	54,535
15:10		53,810	
15:03		54,354	
25:12		56,528	
25:04		59,064	
24:54	24:58	57,071	56,754
24:44		54,354	

Table B-1. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
34:58 34:52 34:43 34:34	34:47	55,622 55,078 54,535 55,984	55,305
50:12 50:04 49:55 49:44	49:59	60,514 58,521 57,977 60,514	59,382
70:26 70:15 70:03 70:02	70:12	59,608 60,151 59,427 58,702	59,472

Table B-2. Raw Data for the 58.8% Mercury Amalgam Condensed Under 19,600 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03 :03 :03	:03	7,247 7,247 7,247	7,247
:16 :15 :15 :16	:155	17,756 18,661 16,669 18,480	17,892
:31 :30 :31 :30	:305	26,996 31,525 29,713 28,626	29,215
:45 :46 :45 :43	:448	38,410 39,135 38,954 36,598	38,274
1:16 1:09 1:02 :52	1:05	51,817 49,824 46,925 44,570	48,284
3:41 3:33 3:24 3:17	3:29	57,434 55,442 54,535 56,529	55,985
8:06 7:57 7:47 7:37	7:52	57,977 56,709 58,883 57,434	57,751
14:40 14:32 14:25 14:16	14:28	57,977 60,152 56,890 56,890	57,977
24:37 24:28 24:20 24:12	24:24	59,970 57,977 60,876 60,333	59,789

Table B-2. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
34:26		57,434	
34:16	34:12	60,876	58,838
34:08		58,340	
33:59		58,702	
49:33		61,601	
49:23	49:18	60,876	61,737
49:13		62,869	
49:04		61,601	
69:38		60,514	
69:29	69:24	59,789	60,605
69:21		61,239	
69:11		60,876	

Table B-3. Raw Data for the 58.8% Mercury Amalgam Condensed Under 29,400 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03		9,240	
:03	:03	12,320	11,233
:03		12,139	
:14		26,271	
:15		27,177	
:18	:155	28,264	26,769
:15		25,365	
:30		38,954	
:32		41,309	
:31	:305	41,309	39,860
:29		37,866	
:45	:455	47,831	48,420
:47		48,013	
:45		49,643	
:45		48,194	
1:25		56,166	
1:14		54,354	
1:04	1:10	51,093	53,358
:55		51,817	
3:08	2:58	57,253	56,392
3:02		55,622	
2:54		56,528	
2:48		56,166	
7:18		61,057	
7:09		56,709	
7:02	7:05	59,064	58,838
6:51		58,521	
14:09	13:57	61,420	60,106
14:01		59,789	
13:53		58,702	
13:46		60,514	
24:39		60,514	
24:31		61,057	
24:24	24:28	60,876	60,831
24:16		60,876	

Table B-3. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
33:49		58,702	
33:40	33:34	61,420	61,827
33:28		63,050	
33:19		64,137	
48:54	48:39	63,232	63,639
48:43		64,862	
48:34		62,326	
48:25		64,137	
69:03	68:51	62,507	62,734
68:55		62,688	
68:47		63,232	
68:39		62,507	

Table B-4. Raw Data for the 58.8% Mercury Amalgam Condensed Under 39,200 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03	:03	15,038	14,857
:03		13,770	
:03		15,763	
:16	:155	36,961	34,968
:15		34,424	
:16		36,779	
:15		31,706	
:30	:303	48,556	46,065
:30		46,744	
:30		44,751	
:31		44,208	
:45	:455	51,998	51,908
:45		53,086	
:46		52,904	
:46		49,643	
1:30	1:14	57,977	56,890
1:18		57,615	
1:08		56,166	
:59		55,803	
4:05	3:54	60,695	59,608
3:57		59,427	
3:50		59,064	
3:42		59,246	
6:16	6:03	60,876	61,012
6:08		59,789	
5:59		61,963	
5:50		61,420	
13:36	13:02	62,144	61,347
13:21		63,775	
13:13		61,963	
12:03		59,064	
12:57		59,789	
24:08	23:57	65,406	63,232
24:01		63,232	
23:54		61,782	
23:46		62,507	

Table B-4. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
33:14		60,514	
33:04	32:59	62,688	62,643
32:54		64,319	
32:43		63,050	
48:17		65,949	
48:10	48:06	65,587	65,406
48:02		65,225	
47:55		64,862	
68:29	68:15	64,319	64,681
68:20		64,862	
68:11		64,862	
68:01		64,681	

Table B-5. Raw Data for the 58.8% Mercury Amalgam Condensed Under 58,800 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03	:03	24,278	23,372
:025		22,829	
:03		23,010	
:15	:158	44,932	44,661
:16		43,121	
:15		44,208	
:17		46,382	
:31	:308	53,991	53,538
:30		52,904	
:32		53,267	
:30		53,991	
:45	:455	56,890	56,166
:46		55,803	
:46		55,803	
:45		56,166	
1:13	1:01	60,514	59,925
1:06		60,333	
:57		60,333	
:49		58,521	
3:33	3:22	63,413	63,187
3:25		63,232	
3:18		62,869	
3:10		63,232	
8:33	8:19	63,775	63,413
8:24		64,137	
8:15		63,594	
8:04		62,144	
12:59	12:47	65,225	65,451
12:51		66,674	
12:42		64,681	
12:34		65,225	
27:29	27:15	67,036	67,036
27:19		65,587	
27:12		67,761	
27:00		67,761	

Table B-5. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
39:11	39:00	63,956	65,632
39:02		67,580	
38:44		66,312	
39:04		64,681	
53:12	52:57	68,486	67,353
53:02		68,123	
52:53		64,137	
52:44		68,667	
75:27	75:13	67,399	67,444
75:17		68,123	
75:08		68,486	
74:59		65,768	

Table B-6. Raw Data for the 58.8% Mercury Amalgam Condensed Under 78,400 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03	:03	32,612	32,854
:03		31,888	
:03		34,062	
:15	:153	53,629	52,814
:16		53,810	
:15		50,911	
:15		52,904	
:29	:298	60,876	58,929
:30		58,159	
:30		58,159	
:30		58,521	
:45	:45	61,057	59,970
:45		58,702	
:45		58,702	
:45		61,420	
1:24	1:13	63,050	63,549
1:17		63,594	
1:09		62,688	
1:00		64,862	
3:15	3:04	65,225	63,956
3:08		63,050	
3:00		63,050	
2:53		64,500	
7:54	7:42	65,586	66,448
7:45		66,312	
7:38		65,587	
7:29		68,305	
12:12	12:05	67,942	68,486
12:03		69,210	
11:55		68,848	
12:11		68,305	
12:03		68,123	
26:47	26:03	67,580	68,758
26:36		69,754	
26:17		70,298	
24:32		67,399	

Table B-6. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
38:12		69,210	
38:02	38:47	69,935	68,486
39:22		65,768	
39:30		69,029	
52:35	52:21	69,935	70,298
52:25		70,660	
52:16		70,479	
52:06		70,116	
74:50		70,660	
74:42	74:36	69,392	70,615
74:31		71,747	
74:20		70,660	

Table B-7. Raw Data for the 58.8% Mercury Amalgam Condensed Under 98,000 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:025	:025	40,222	41,067
:025		42,758	
:025		40,222	
:16	:153	57,615	57,977
:15		58,702	
:15		57,977	
:15		57,615	
:30	:30	62,144	61,556
:30		61,239	
:30		62,326	
:30		60,514	
:45	:45	61,601	63,277
:45		63,050	
:45		64,862	
:45		63,594	
1:19	1:07	65,768	64,817
1:10		66,312	
1:03		62,688	
:55		64,500	
3:49	3:39	66,855	67,444
3:42		67,399	
3:35		69,210	
3:29		66,312	
6:07	5:54	67,580	69,120
5:59		68,848	
5:51		70,116	
5:39		69,935	
13:19	13:04	66,855	69,799
13:09		69,754	
12:59		71,022	
12:52		71,566	
26:03	25:49	71,747	71,430
25:54		68,486	
25:45		72,109	
25:34		73,378	

Table B-7. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
43:33		70,841	
42:22	42:17	74,283	73,151
42:11		73,559	
42:01		73,921	
51:57		71,566	
51:46	51:40	71,566	72,427
51:34		74,465	
51:24		72,109	
75:14		69,573	
75:04	75:02	70,841	
74:59		73,921	71,475
74:50		71,566	

Table B-8. Raw Data for the 58.8% Mercury Amalgam Condensed Under 117,600 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03 :03 :03	:03	49,462 48,013 48,918	48,798
:15 :15 :16 :16	:155	61,601 60,876 61,420 60,514	61,103
:30 :31 :29 :31	:303	63,050 62,326 62,326 63,956	62,915
:45 :45 :47 :47	:46	64,862 63,775 64,500 65,043	64,545
1:23 :58 1:25 1:17 1:09 1:01	1:12	65,043 67,399 62,326 65,768 65,406 64,500	65,074
2:53 2:46 2:39 2:30	2:42	67,036 68,486 64,862 69,029	67,353
7:45 7:32 7:17 7:05	7:25	70,116 71,747 70,660 67,399	69,981
12:36 12:28 12:21 12:09	12:24	69,392 66,855 71,566 68,123	68,984
27:55 27:39 27:28 27:13	27:34	71,566 71,371 71,385 70,479	72,200

Table B-8. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
41:51	41:35	73,740	74,510
41:39		75,008	
41:30		75,733	
41:19		73,559	
50:18	50:41	70,298	73,688
50:12		72,472	
50:02		76,276	
49:56		73,378	
74:43	74:30	72,291	74,918
74:35		75,371	
74:25		75,733	
74:16		76,276	

Table B-9. Raw Data for the 70% Mercury Amalgam Condensed Under 86,200 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03	:03	33,337	33,760
:03		34,062	
:03		33,881	
:57	:39	61,057	59,940
:36		61,601	
:20		56,166	
:50		63,413	
:46		58,340	
:25		59,064	
2:36	2:04	66,674	66,040
2:06		64,862	
1:52		66,674	
1:40		65,949	
5:33	5:14	67,218	67,623
5:20		68,486	
5:08		66,312	
4:55		68,486	
11:54	11:33	67,218	69,075
11:43		69,754	
11:25		68,848	
11:09		70,479	
22:12	21:51	71,747	70,570
21:58		68,486	
21:27		70,660	
21:46		71,385	
35:56	35:34	70,660	70,524
35:40		71,203	
35:25		69,935	
35:13		70,298	
42:13	41:51	72,834	70,898
41:59		71,022	
41:42		69,573	
41:30		70,163	
75:42	74:54	67,580	68,984
74:58		67,580	
74:50		69,935	
74:42		70,841	

Table B-10. Raw Data for the 58.8% Mercury Amalgam Condensed Under 86,200 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:08		49,462	
:07	:06	46,382	44,434
:05		39,859	
:04		42,033	
1:13	1:01	65,587	61,873
:55		64,500	
:37		51,455	
1:17		65,949	
2:15		68,123	
2:01	2:07	65,587	66,855
4:14		66,855	
3:56	3:42	67,399	68,078
3:36		68,848	
3:01		69,210	
15:52		67,399	
15:29	15:06	66,855	69,102
15:04		71,022	
14:43		70,116	
14:23		70,116	
27:02		69,392	
26:47		70,660	
26:29	26:39	69,392	70,117
26:16		71,022	
36:56	36:01	70,297	70,949
36:33		71,022	
36:07		71,022	
35:58		72,109	
34:30		70,297	
74:30		69,029	
74:25		69,573	
74:18	74:21	67,761	68,758
74:12		68,667	

Table B-11. Raw Data for the 50% Mercury Amalgam Condensed Under 86,200 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
	:07		42,124
:07		42,939	
:07		41,309	
1:00		59,427	
:41	:41	53,991	56,951
:23		57,434	
2:12	1:57	62,869	63,172
1:57		64,137	
1:42		62,507	
5:05		65,225	
4:55	4:54	65,768	65,829
4:42		66,493	
12:09		68,667	
11:54	11:40	67,217	67,254
11:40		65,949	
11:24		67,036	
11:11		67,399	
26:47		69,391	
26:23	26:27	68,667	68,968
26:10		68,848	
43:59		71,747	
43:23		70,660	
43:07	43:30	71,022	71,143
43:04		66,312	
73:55	73:51	68,123	66,991
73:47		66,493	
73:39		67,036	

Table B-12. Raw Data for the 40% Mercury Amalgam Condensed Under 86,200 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:06	:04	40,041	35,088
:03		32,612	
:03		32,612	
:54	:42	55,803	56,045
:41		56,166	
:28		56,166	
:58		56,709	
:45		56,709	
:23		54,716	
3:03	2:42	59,246	58,566
2:50		60,333	
2:33		50,890	
2:20		57,796	
6:43	6:22	60,514	61,284
6:31		63,413	
6:02		60,695	
10:52	10:32	65,043	64,364
10:42		63,775	
10:23		65,587	
10:11		63,050	
23:26	23:05	63,050	63,503
23:11		61,782	
22:57		63,413	
22:45		65,768	
36:24	35:58	61,498	61,847
36:02		59;970	
35:50		63,232	
35:35		62,688	
50:01	49:43	66,130	65,542
49:48		65,225	
49:36		65,225	
49:26		65,587	
72:35	72:23	61,601	63,413
72:29		64,319	
72:16		63,956	
72:12		63,775	

Table B-13. Raw Data for the 58.8% Mercury Amalgam Condensed Under 78,400 psi. for Five Minutes

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03		51,093	
:035	:033	56,528	54,218
:03		52,723	
:035		56,528	
2:00		67,218	
1:52	1:36	65,225	65,632
1:28		64,137	
1:03		65,949	
3:30		63,413	
3:17	3:11	61,601	64,138
3:05		66,312	
2:53		65,225	
6:17		68,486	
6:03		70,298	
6:25	6:02	71,203	69,271
5:58		67,399	
5:50		69,573	
5:37		68,667	
15:52		73,196	
15:37		71,928	
15:26	15:32	72,834	72,789
15:12		73,196	
24:37		69,573	
24:26	24:34	72,109	71,339
24:13		71,203	
23:59		72,472	
35:52		72,109	
35:37	35:31	68,848	69,890
35:25		70,298	
35:10		68,305	
48:08		69,935	
47:57	47:47	73,196	72,245
47:38		74,646	
47:24		71,203	

Table B-13. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
72:29		71,203	
72:14	73:20	73,196	72,019
72:01		71,385	
74:21		69,935	
74:11		72,472	
74:02		73,921	

Table B-14. Raw Data for the 58.8% Mercury Amalgam Condensed Under 78,400 psi. for Ten Minutes

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:03 :03 :03	:03	58,702 59,789 57,977	58,823
1:30 1:47 2:10 2:30	1:59	65,225 63,775 63,775 64,862	64,409
2:30 2:58 3:15 3:34	3:04	67,036 68,848 71,203 69,210	69,074
5:25 5:42 6:00 6:19	5:52	69,935 68,486 66,855 69,754	68,758
13:35 13:15 12:55 12:37	13:06	71,022 68,848 68,848 71,022	69,935
24:55 24:36 24:19 24:01	24:28	72,472 70,841 74,646 72,472	72,608
37:12 36:25 39:28 39:09	38:04	70,479 76,458 70,298 71,022	72,064
55:09 54:33 47:07 46:30	50:50	73,196 73,740 71,928 72,472	72,834
75:04 74:39 73:59 73:30	74:18	73,921 71,022 75,008 76,458	74,102

Table B-15. Raw Data for the 58.8% Mercury Amalgam Condensed Under 78,400 psi. for One Minute At Mouth Temperature (37°C)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
1:20	1:05	61,239	60,695
1:10		59,789	
1:00		61,963	
:51		59,789	
2:59	2:46	62,326	63,141
2:51		63,956	
2:41		63,232	
2:31		63,050	
5:45	5:31	63,413	63,730
5:36		61,963	
5:27		65,949	
5:14		63,594	
14:29	14:16	65,768	65,995
14:21		66,674	
14:11		66,674	
14:03		64,862	
24:45	24:30	66,855	68,305
24:33		67,399	
24:25		68,848	
24:15		70,116	
37:29	37:16	65,768	68,124
37:21		70,479	
37:12		67,761	
37:02		68,486	
51:11	50:58	70,660	70,433
51:02		69,753	
50:54		69,935	
50:44		71,385	
69:09	68:56	71,747	71,747
69:00		69,573	
68:52		72,834	
68:43		72,834	

Table B-16. Raw Data for the 58.8% Mercury Amalgam Hand Condensed at 550 psi. for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
1:23		11,596	
1:14	1:14	12,501	12,109
1:06		10,871	
1:22		12,864	
1:11		13,045	
1:05		11,777	
2:33		17,756	
2:42		15,581	
3:09	2:48	17,574	17,242
3:01		18,843	
2:46		16,306	
2:38		17,393	
6:26		27,906	
6:17		23,191	
6:23	6:14	19,930	23,343
6:15		19,930	
6:06		22,829	
5:56		26,271	
15:03		42,758	
14:55		31,525	
14:48		39,497	
14:42	14:32	38,772	35,602
13:56		26,815	
13:48		34,243	
24:42		43,664	
24:33		40,222	
24:24	24:16	47,469	44,178
24:16		47,107	
23:33		41,852	
23:37		44,751	
38:56		43,483	
38:36		47,831	
38:02	38:43	48,918	45,204
39:01		42,939	
38:53		45,657	
38:37		42:396	

Table B-16. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
47:49		44,570	
47:40	47:29	44,570	45,627
47:31		46,020	
47:25		46,563	
47:19		45,838	
47:11		46,201	
73:39	72:59	46,744	46,382
73:32		47,831	
73:22		44,570	
73:17		47,107	
72:49		46,020	
71:14		46,020	

Table B-17. Raw Data for Low Amplitude Ultrasonically Condensed Amalgam at Zero Pressure for Twenty Seconds

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
:05	:045	0	0
:04		0	
1:12	1:11	22,466	23,010
1:10		22,466	
1:24	1:25	28,264	28,264
1:25		28,264	
1:31	1:31	29,713	29,351
1:30		28,989	
1:49	1:50	35,511	36,055
1:50		36,598	
4:01	3:30	46,744	48,420
3:36		49,462	
3:18		47,650	
3:05		49,824	
6:09	5:50	50,730	49,779
5:54		50,005	
5:43		49,281	
5:34		49,100	
13:13	12:51	53,086	53,131
12:56		55,441	
12:43		53,629	
12:30		50,368	
24:39	24:24	51,274	51,319
24:28		50,730	
24:23		52,547	
24:04		50,730	
36:44	36:28	56,347	55,079
36:35		55,079	
36:22		55,260	
36:10		53,629	
49:22	49:07	54,354	52,905
49:12		52,180	
48:49		51,817	
49:03		53,267	

Table B-17. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
73:32		54,897	
72:20	72:16	54,897	54,399
72:10		53,086	
72:00		54,716	

Table B-18. Raw Data for High Amplitude Ultrasonically Condensed Amalgam at 9,800 psi. for Ten Seconds

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
1:07		36,236	
1:08	1:08	36,961	36,010
1:08		36,055	
1:08		34,786	
1:22		40,403	
1:20	1:20	40,946	40,475
1:19		39,859	
1:20		39,678	
1:20		41,490	
1:33		44,932	
1:30		45,657	
1:32	1:31	46,744	45,295
1:30		53,845	
3:18		51,636	
3:17		49,281	
3:09	3:10	50,730	49,689
2:56		47,107	
6:56		51,274	
6:47	6:38	54,716	52,542
6:28		52,180	
6:19		51,998	
14:26		50,730	
14:18		55,078	
14:11	14:10	54,716	53,720
13:45		54,354	
27:26		56,166	
27:10	27:07	56,166	55,441
27:01		55,079	
26:49		54,354	
37:15		55,079	
37:08		56,528	
37:00	37:04	54,535	55,713
36:52		56,709	
50:27		55,803	
50:18	50:15	54,716	53,901
50:11		52,542	
50:03		52,542	

Table B-18. (Continued)

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
74:49	74:36	53,629	55,215
74:42		54,173	
74:32		56,528	
74:22		56,528	

Table B-19. Raw Data for 58.8% Mercury Amalgam Hand Condensed with 0.5 mm Condenser at 34,000 psi for One Minute

Time (Hr:Min)	Average (Hr:Min)	Compressive Strength (psi)	Average (psi)
1:08		18,843	
1:16	1:19	18,299	19,160
1:22		18,842	
1:30		20,654	
3:17		28,626	
3:23	3:32	25,908	26,905
3:29		27,539	
3:58		25,546	
6:43		43,121	
6:48	6:53	39,859	42,668
6:55		46,019	
7:04		41,671	
16:34		51,093	
16:52	16:53	46,744	49,190
16:59		47,107	
17:06		51,817	
26:16		53,991	
26:24	26:29	51,455	53,131
26:33		53,267	
26:41		53,810	
36:30		50,730	
36:39	36:47	49,281	49,100
36:55		47,831	
37:03		48,556	
59:17		50,730	
59:25	59:29	53,629	52,542
59:34		52,904	
59:41		52,904	
79:42	79:57	52,180	54,354
79:50		53,991	
80:03		55,078	
80:11		56,166	

Table B-20. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 9.800 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:163	16.3	1.212	13.090	4.117
:037	3.7	0.568	3,442	3.536
:315	31.5	1.498	21,108	4,324
:458	45.8	1.661	28.853	4.460
1:01	61	1.785	35,149	4,545
2:32	152	2.182	52,950	4.724
8:37	517	2.713	54,807	4.739
15:14	914	2.961	54,535	4.736
24:58	1498	3.176	56,754	4.754
34:47	2087	3.320	55,305	4.742
49:59	2999	3.477	59,382	4.773
70:12	4212	3.624	59,472	4.774

Table B-21. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 19,600 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	7,247	3.855
:155	15.5	1.190	17,892	4.252
:305	30.5	1.484	29,215	4.465
:448	44.8	1.651	38,274	4.583
1:05	65	1.813	48,284	4.683
3:29	209	2.320	55,985	4.748
7:52	472	2.674	57,751	4.762
14:28	868	2.938	57,977	4.763
24:24	1464	3.166	59,789	4.776
34:12	2052	3.312	58,838	4.769
49:18	2958	3.471	61,737	4.790
69:24	4164	3.620	60,605	4.782

Table B-22. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 29,400 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	11,233	4.050
:155	15.5	1.190	26,769	4.427
:305	30.5	1.484	39,860	4.600
:455	45.5	1.658	48,420	4.684
1:10	70	1.845	53,358	4.726
2:58	178	2.250	56,392	4.751
7:05	425	2.628	58,838	4.769
13:57	837	2.923	60,106	4.779
24:28	1468	3.166	60,831	4.784
33:34	2014	3.303	61,827	4.791
48:39	2919	3.465	63,639	4.804
68:51	4131	3.616	62,734	4.797

Table B-23. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 39,200 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	14,857	4.172
:155	15.5	1.190	34,968	4.543
:303	30.3	1.482	46,065	4.664
:455	45.5	1.658	51,908	4.715
1:14	74	1.869	56,890	4.755
3:54	234	2.369	59,608	4.775
6:03	363	2.560	61,012	4.785
13:02	782	2.893	61,347	4.787
23:57	1437	3.157	63,232	4.800
32:59	1979	3.296	62,643	4.796
48:06	2886	3.460	65,406	4.813
68:15	4095	3.612	64,681	4.811

Table B-24. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 58,800 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	23,372	4.368
:158	15.8	1.198	44,661	4.650
:308	30.8	1.488	53,538	4.729
:455	45.5	1.658	56,166	4.749
1:01	61	1.785	59,925	4.778
3:22	202	2.305	63,187	4.800
8:19	499	2.698	63,413	4.802
12:47	767	2.886	65,451	4.816
27:15	1635	3.213	67,036	4.826
39:00	2340	3.369	65,632	4.817
52:57	3177	3.502	67,353	4.828
75:13	4513	3.654	67,444	4.828

Table B-25. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 78,400 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	32,854	4.516
:153	15.3	1.185	52,814	4.723
:298	29.8	1.474	58,929	4.770
:45	45	1.653	59,970	4.778
1:13	73	1.863	63,549	4.803
3:04	184	2.265	63,956	4.806
7:42	462	2.664	66,448	4.822
12:05	725	2.860	68,486	4.835
26:03	1563	3.194	68,758	4.837
38:47	2327	3.367	68,486	4.835
52:21	3141	3.497	70,298	4.846
74:36	4476	3.650	70,615	4.849

Table B-26. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 98,000 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:025	2.5	0.398	41,067	4.619
:153	15.3	1.184	57,977	4.763
:30	30	1.477	61,556	4.789
:45	45	1.653	63,277	4.801
1:07	67	1.826	64,817	4.811
3:39	219	2.340	67,444	4.828
5:54	354	2.549	69,120	4.839
13:04	784	2.894	69,799	4.843
24:49	1549	3.190	71,430	4.853
42:17	2537	3.404	73,151	4.864
51:40	3100	3.491	72,427	4.860
75:02	4502	3.653	71,475	4.853

Table B-27. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 117,600 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	48,798	4.688
:155	15.5	1.190	61,103	4.786
:303	30.3	1.481	62,915	4.798
:46	46	1.663	64,545	4.810
1:12	72	1.716	65,074	4.813
2:42	162	2.209	67,353	4.828
7:25	445	2.648	69,981	4.844
12:24	744	2.871	68,984	4.838
27:34	1654	3.218	72,200	4.858
41:35	2495	3.397	74,510	4.872
50:41	3041	3.483	73,688	4.867
74:30	4470	3.650	74,918	4.874

Table B-28. Logarithmic Data for 70% Mercury Amalgam Condensed at 86,200 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	33,760	4.528
:39	39	1.591	59,949	4.777
2:04	124	2.093	66,040	4.820
5:14	314	2.497	67,623	4.830
11:33	693	2.840	69,075	4.838
21:51	1311	3.117	70,570	4.848
35:34	2134	3.329	70,524	4.848
41:51	2511	3.400	70,898	4.850
74:54	4494	3.652	68,984	4.838

Table B-29. Logarithmic Data for 50% Mercury Amalgam Condensed at 86,200 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:07	7	0.845	42,124	4.624
:41	41	1.612	56,951	4.755
1:57	117	2.068	63,172	4.800
4:54	294	2.468	65,829	4.818
11:40	700	2.845	67,254	4.828
26:27	1587	3.200	68,968	4.838
43:30	2610	3.416	71,143	4.852
73:51	4431	3.646	66,991	4.826

Table B-30. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 86,200 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:06	6	0.778	44,434	4.647
1:01	61	1.785	61,873	4.791
2:07	127	2.104	66,855	4.825
3:42	222	2.346	68,078	4.832
15:06	906	2.957	69,102	4.839
26:39	1599	3.204	70,117	4.846
36:01	2161	3.334	70,949	4.850
74:21	4461	3.649	68,758	4.837

Table B-31. Logarithmic Data for 40% Mercury Amalgam Condensed at 86,200 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:04	4	0.602	35,088	4.544
:42	42	1.623	56,045	4.748
2:42	162	2.209	58,566	4.767
6:22	382	2.582	61,284	4.787
10:32	632	2.800	64,364	2.808
23:05	1385	3.141	63,503	4.803
35:58	2158	3.334	61,847	4.791
49:43	2983	3.474	65,542	4.816
72:23	4343	3.638	63,413	4.802

Table B-32. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 78,400 si for Five Minutes

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:033	3.3	0.518	54,218	4.734
1:36	96	1.982	65,632	4.817
3:11	191	2.281	64,138	4.807
6:02	362	2.558	69,271	4.840
15:32	932	2.969	72,789	4.861
24:34	1474	3.168	71,339	4.853
35:31	2131	3.328	69,890	4.844
47:47	2820	3.450	72,245	4,858
73:20	4400	3.643	72,019	4.857

Table B-33. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 78,400 psi for Ten Minutes

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
:03	3	0.477	58,823	4.769
1:49	119	2.075	64,409	4.809
3:04	184	2.264	69,074	4.839
5:52	352	2.546	68,758	4.837
13:06	786	2.895	69,935	4.844
24:28	1468	3.166	72,608	4.861
38:04	2284	3.359	72,064	4.857
50:50	3050	3.484	72,834	4.862
74:18	4458	3.649	74,102	4.870

Table B-34. Logarithmic Data for 58.8% Mercury Amalgam Condensed at 78,400 psi for One Minute at Mouth Temperature (37°C)

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
1:05	65	1.813	60,695	4.783
2:46	166	2.220	63,141	4,800
5:31	331	2.520	63,730	4.804
14:16	856	2.933	65,995	4.819
24:30	1470	3.167	68,305	4.834
37:16	2236	3.349	68,124	4.833
50:58	3058	3.485	70,433	4.847
68:56	4136	3.616	71,747	4.856

Table B-35. Logarithmic Data for 58.8% Mercury Amalgam Hand Condensed at 550 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
1:14	74	1.869	12,109	4.083
2:48	168	2.225	17,242	4.236
6:14	374	2.573	23,343	4.368
14:32	872	2.940	35,602	4.552
24:16	1456	3.163	44,178	4.645
38:43	2323	3.365	45,204	4.655
47:29	2849	3.455	45,627	4.659
72:59	4379	3.641	46,382	4.666

Table B-36. Logarithmic Data for 58.8% Mercury Amalgam Hand Condensed at 34,000 psi for One Minute

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
1:19	79	1.897	19,160	4.282
3:32	212	2.326	26,905	4.430
6:53	413	2.616	42,668	4.630
16:53	1013	3.000	49,190	4.690
26:29	1589	3.201	53,131	4.725
36:47	2207	3.343	49,100	4.691
59:29	3569	3.553	52,542	4.720
79:57	4797	3.681	54,354	4.735

Table B-37. Logarithmic Data for 58.8% Mercury Amalgam Low Amplitude, Ultrasonically Radiated at Zero Pressure for Twenty Seconds

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
1:11	71	1.852	23,010	4.362
1:25	85	1.929	28,264	4.451
1:31	91	1.959	29,351	4.467
1:50	110	2.041	36,055	4.556
3:30	210	2.322	48,420	4.685
5:50	350	2.544	49,779	4.696
12:51	771	2.887	53,131	4.725
24:24	1464	3.166	51,319	4.710
36:28	2188	3.340	55,079	4.741
49:07	2947	3.469	52,905	4.723
72:16	4336	3.636	54,399	4.735

Table B-38. Logarithmic Data for 58.8% Mercury Amalgam High Amplitude, Ultrasonically Condensed at 9,800 psi for Ten Seconds

Time (Hr:Min)	Min.	Log t	P (psi)	Log P
1:31	91	1.959	45,295	4.655
1:20	80	1.903	40,475	4.606
1:08	68	1.833	36,010	4.557
3:10	190	2.279	49,689	4.695
6:38	398	2.600	52,542	4.720
14:10	850	2.929	53,720	4.730
27:07	1627	3.211	55,441	4.744
37:04	2224	3.346	55,713	4.745
50:15	3015	3.479	53,901	4.732
74:36	4476	3.651	55,215	4.742

Table B-39. Density Data for the 48.3% Mercury Amalgam Condensed for One Minute

Condensing Pressure (psi)	Density (gm/cm^3)	Average (gm/cm^3)
19,600	10.9387 10.9605	10.9496
39,200	10.7567 10.7239	10.7403
58,800	11.2260 10.1942	10.7101
78,400	10.7029 10.6871	10.6950
98,000	10.6293 10.6833	10.6563
117,600	10.6904 10.6207	10.6555

Table B-40. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 19,600 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
109		115	
70.5		134	
80.7		205	
123		142	
123		148	
115		175	
118		162	
78.5		210	
116	105.49	123	157.73
116		185	
117		202	
105		127	
105		171	
		151	
110		116	
95.6			

Table B-41. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 39,200 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
139		172	
131		166	
148		204	
160		190	
170		198	
148		198	
112		170	
149	135.56	193	185.5
127		182	
111		182	
96			

Table B-42. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 58,800 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
106		234	
136		158	
122		174	
146		192	
121		219	
96		170	
150		141	
112	125.8	159	
139		170	
136		170	
120		179	
		172	

Table B-43. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 78,400 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
76.6		162	
96		162	
128		162	
160		224	
124		238	
96		160	
121	122.71	198	201.8
121		235	
158		227	
105		202	
160		230	
131		199	
121		185	
138		185	
105		258	

Table B-44. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 98,000 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
129		202	
152		262	
133		262	
160		245	
141		271	
133		254	
134	143.87	275	246.33
126		196	
118		214	
133		270	
150		307	
139		290	
160		290	
154		272	
196		285	

Table B-45. Microhardness Data for the 48.3% Mercury Amalgam Condensed at 117,600 psi for One Minute

Matrix		Particle	
Knoop Hardness	Average	Knoop Hardness	Average
107		254	
135		208	
140		276	
171		230	
173		276	
104		191	
115	127.93	238	244.00
130		238	
82		290	
89		263	
100		208	
171		254	
127		246	
102			
173			

Table B-46. X-ray Data for 58.8% Mercury Amalgam Hand Condensed at 550 psi for One Minute

Ag_2Hg_3 $2\theta = 38.0^\circ$			Sn_8Hg $2\theta = 32.2^\circ$			$Ag_3Sn(Hg)$ $2\theta = 39.6^\circ$		
Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$
8.6	.012	48.3	15.1	.0024	9.6	11.9	.0045	18.1
11.9	.0143	57.6	27.0	.0022	8.8	21.8	.0028	11.2
19.5	.0162	65.3	59.5	.0028	11.2	43.3	.0019	7.6
30.2	.0169	68.1	102.1	.0027	10.8	54.2	.0013	5.2
41.0	.0208	83.7	149.0	.0026	10.4	63.5	.0011	4.4
63.0	.0218	87.9	205.3	.0033	13.1	97.0	.0008	3.1
107.5	.022	88.7	240.9	.0033	13.1	141.9	.0007	2.8
155.9	.0232	93.4				199.2	.0006	2.4
201.8	.0248	100.0				235.5	.0005	2.0
233.0	.0248	100.0						

Table B-47. X-ray Data for 58.8% Mercury Amalgam Ultrasonically Condensed with High Amplitude at 9,800 psi for Ten Seconds

Ag_2Hg_3 $2\theta = 38.0^{\circ}$			Sn_8Hg $2\theta = 32.2^{\circ}$			$Ag_3Sn(Hg)$ $2\theta = 39.6^{\circ}$		
Time (Min)	Weight (gm)	I/I_{∞} x 100	Time (Min)	Weight (gm)	I/I_{∞} x 100	Time (Min)	Weight (gm)	I/I_{∞} x 100
13.6	.0302	85.5	20.5	.0021	5.9	14.5	.0044	12.1
17.0	.0319	90.3	33.5	.0025	7.1	33.7	.0037	10.4
25.2	.0328	92.9	51.0	.0025	7.1	61.3	.0033	9.3
40.2	.0348	98.5	103.3	.0024	6.8	97.0	.0026	7.3
64.0	.0353	100.0	128.0	.0021	5.9	146.0	.0026	7.3
119.8	.0347	98.3	187.0	.0022	6.2	202.8	.0025	7.0
167.0	.0311	88.1	210.3	.002	5.6	239.8	.0023	6.5
205.5	.0331	93.7	244.5	.0017	4.7	263.5	.0024	6.7
240.8	.0333	94.3						

Table B-48. X-ray Data for 58.8% Mercury Amalgam Condensed at 9,800 psi for One Minute

Ag_2Hg_3 $2\theta = 38.0^{\circ}$			Sn_8Hg $2\theta = 32.2^{\circ}$			$Ag_3Sn(Hg)$ $2\theta = 39.6^{\circ}$		
Time (Min)	Weight (gm)	$I/I_{\infty} \times 100$	Time (Min)	Weight (gm)	$I/I_{\infty} \times 100$	Time (Min)	Weight (gm)	$I/I_{\infty} \times 100$
3.50	.0144	64.9	7.1	.0035	15.6	2.8	.0092	41.2
14.5	.0188	84.3	18.0	.0041	18.3	13.8	.0059	26.4
33.5	.0214	96.0	28.8	.0045	20.1	24.5	.0061	27.3
68.5	.0211	94.6	64.8	.0049	21.9	52.8	.0044	19.7
104.5	.0223	100.0	97.0	.0043	19.2	102.6	.0052	23.3
146.0	.0223	100.0	153.9	.0047	21.0	147.6	.0045	20.1
193.5	.0221	99.1	198.6	.0044	19.7	202.8	.0052	23.3

Table B-49. X-ray Data for 58.8% Mercury Amalgam Condensed at 19,600 psi for One Minute

Ag_2Hg_3 $2\theta = 38.0^\circ$			Sn_8Hg $2\theta = 32.2^\circ$			$Ag_3Sn(Hg)$ $2\theta = 39.6^\circ$		
Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$
3.3	.0221	70.3	7.2	.0068	21.6	2.5	.014	44.5
12.0	.0249	79.2	19.5	.0078	24.8	12.8	.0168	53.5
27.7	.0290	92.3	31.7	.0076	24.2	37.3	.0091	28.9
61.0	.0272	86.6	56.3	.0077	24.5	86.3	.0108	34.3
88.9	.0293	93.3	117.3	.0071	22.6	122.8	.0092	29.2
125.4	.0314	100.0	171.0	.008	25.4	185.5	.0083	26.4
186.3	.0292	92.9	240.0	.0078	24.8	245.7	.0088	28.0
236.1	.0301	95.8						

Table B-50. X-ray Data for 58.8% Mercury Amalgam Condensed at 39,200 psi for One Minute

Ag_2Hg_3 $2\theta = 38.0^\circ$			Sn_8Hg $2\theta = 32.2^\circ$			$Ag_3Sn(Hg)$ $2\theta = 39.6^\circ$		
Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$	Time (Min)	Weight (gm)	$I/I_\infty \times 100$
3.5	0.0221	80.3	9.9	.007	25.4	4.5	.005	18.1
6.5	0.0240	87.2	21.5	.0075	27.2	15.0	.0052	18.9
15.0	0.0244	88.7	34.5	.0068	24.7	27.2	.005	18.1
37.8	0.0264	96.0	46.0	.0083	30.1	38.5	.0049	17.8
64.5	0.0257	93.4	69.8	.008	29.0	62.5	.0044	16.0
88.0	0.0264	100.0	103.8	.0075	27.2	99.2	.0049	17.8
123.8	0.0275	95.2	127.5	.0074	26.9	133.0	.0045	16.3
156	.0262	97.8	162.5	.0074	26.9	158.0	.0054	19.6
204.7	.0269	97.8	196.8	.0071	25.8	202.3	.0049	17.8
239	.0269		242.7	.0071	25.8	243.0	.0049	17.8

Table B-51. X-ray Data for 58.8% Mercury Amalgam Condensed at 117,600 psi for One Minute

Ag_2Hg_3 $2\theta = 38.0^\circ$			Sn_8Hg $2\theta = 32.2^\circ$			$Ag_3Sn(Hg)$ $2\theta = 39.6^\circ$		
Time (Min)	Weight (gm)	I/I_∞ x 100	Time (Min)	Weight (gm)	I/I_∞ x 100	Time (Min)	Weight (gm)	I/I_∞ x 100
3.0	.0179	78.5	10.9	.0085	37.2	5.0	.005	21.9
14.5	.0202	88.5	20.6	.0095	41.6	15.0	.0043	18.8
36.8	.0215	94.2	31.8	.0109	47.8	37.5	.0054	23.6
59.5	.0211	92.5	55.8	.0111	48.6	60.2	.005	21.9
102.5	.0218	95.6	98.9	.0118	51.7	103.3	.0047	20.6
136.5	.0228	100.0	133.0	.0108	47.3	137.4	.0042	18.4
181.5	.0212	92.8	177.8	.0115	50.4	182.0	.0052	22.8

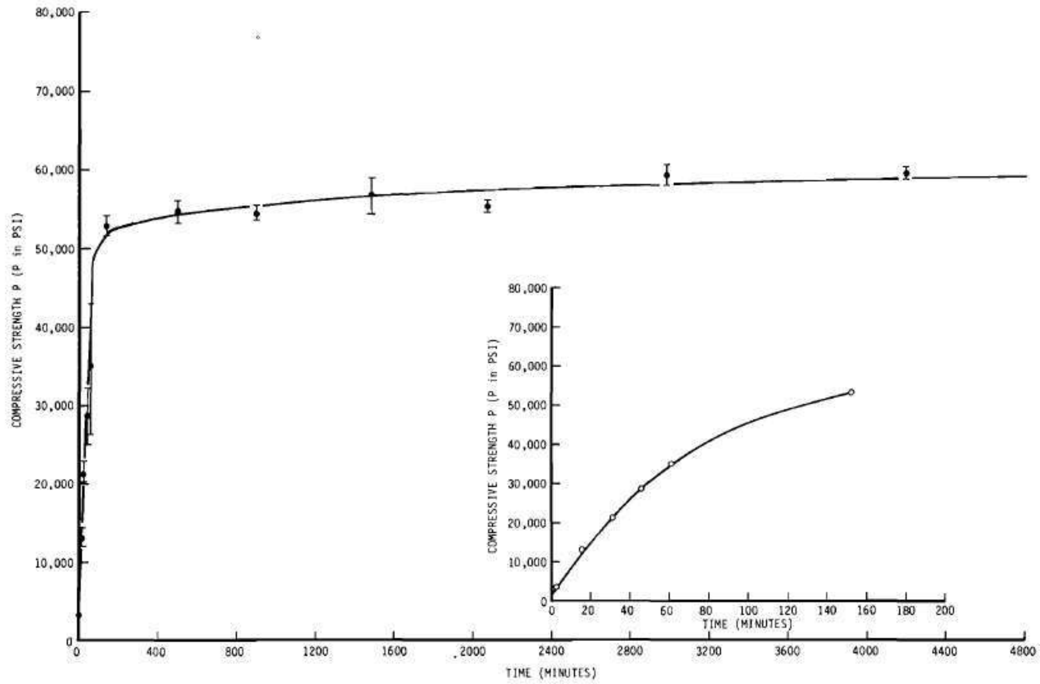

Figure B-1. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 9,800 psi for 1 Minute.

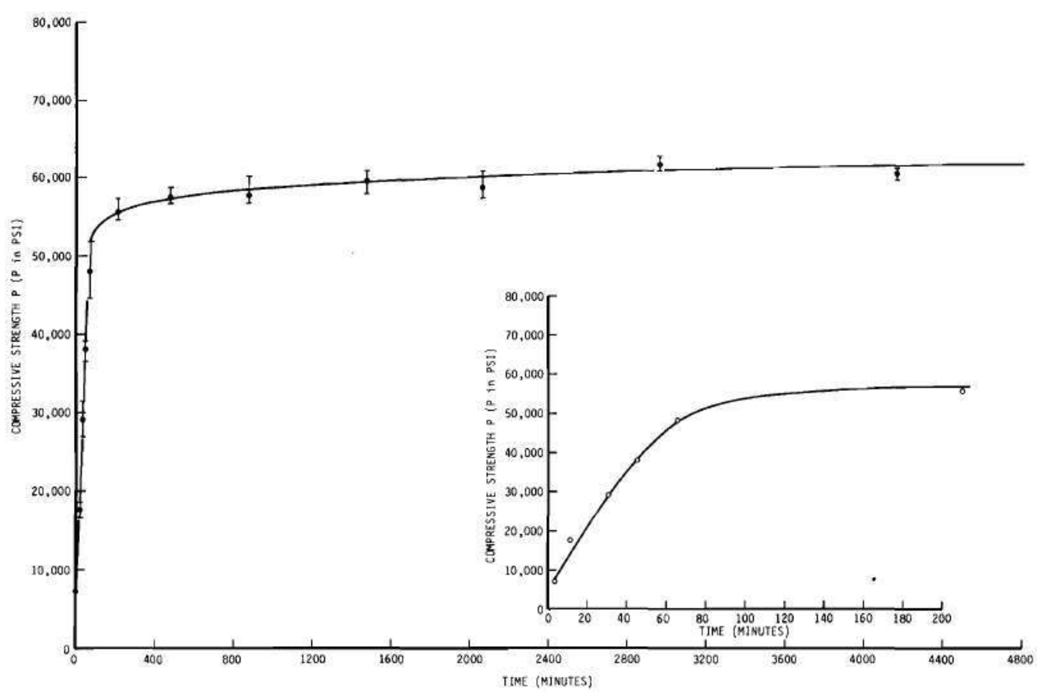

Figure B-2. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 19,600 psi for 1 Minute.

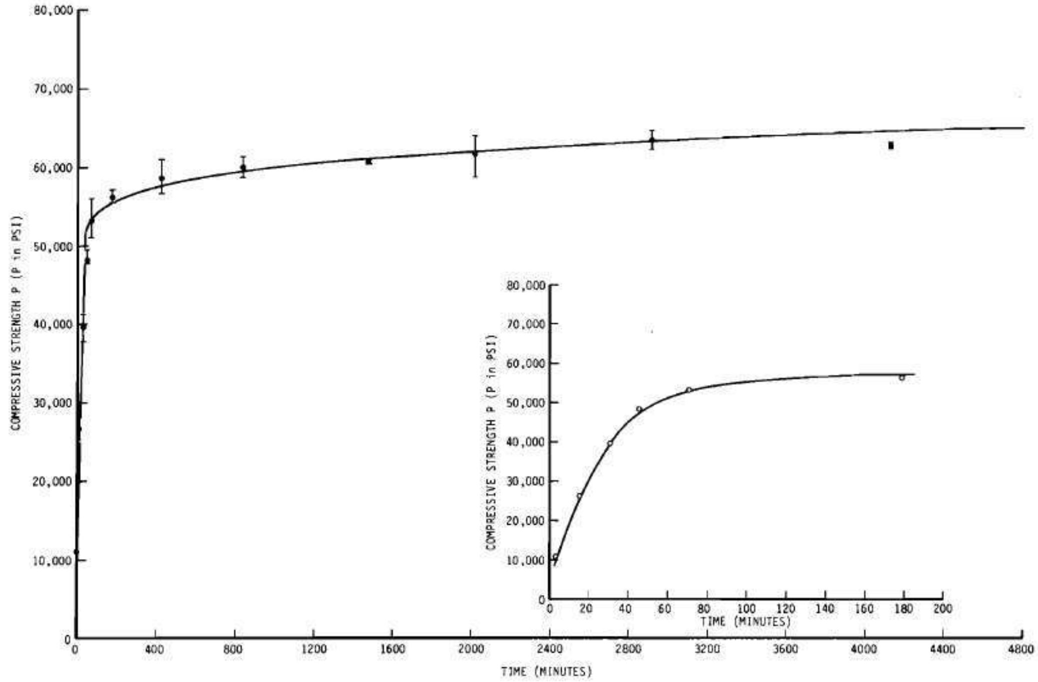

Figure B-3. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 29,400 psi for 1 Minute.

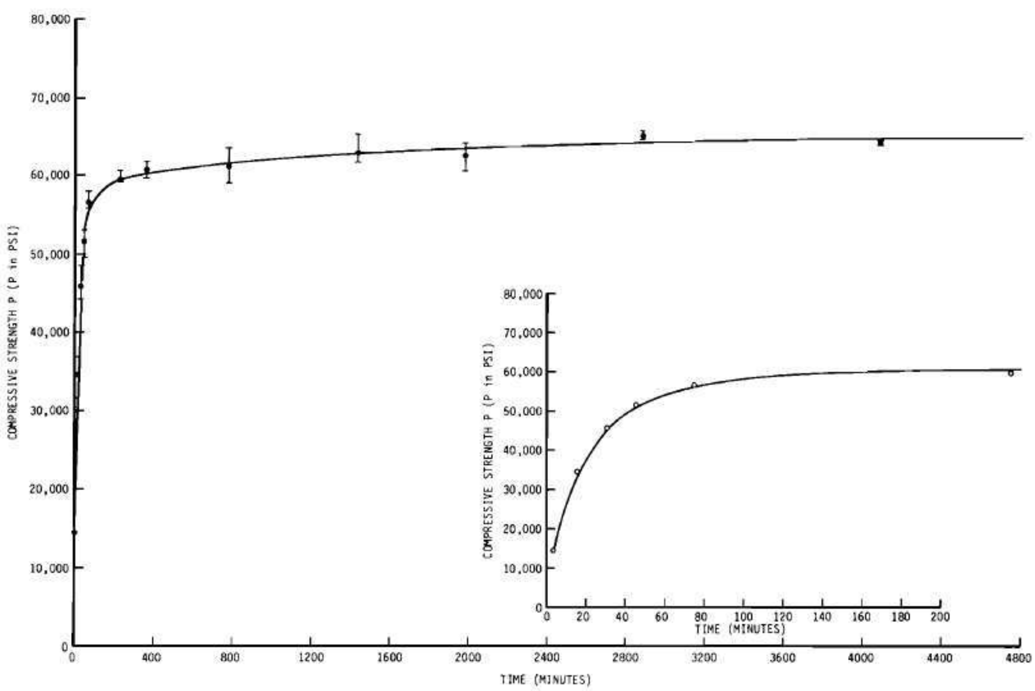

Figure B-4. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 39,200 psi for 1 Minute.

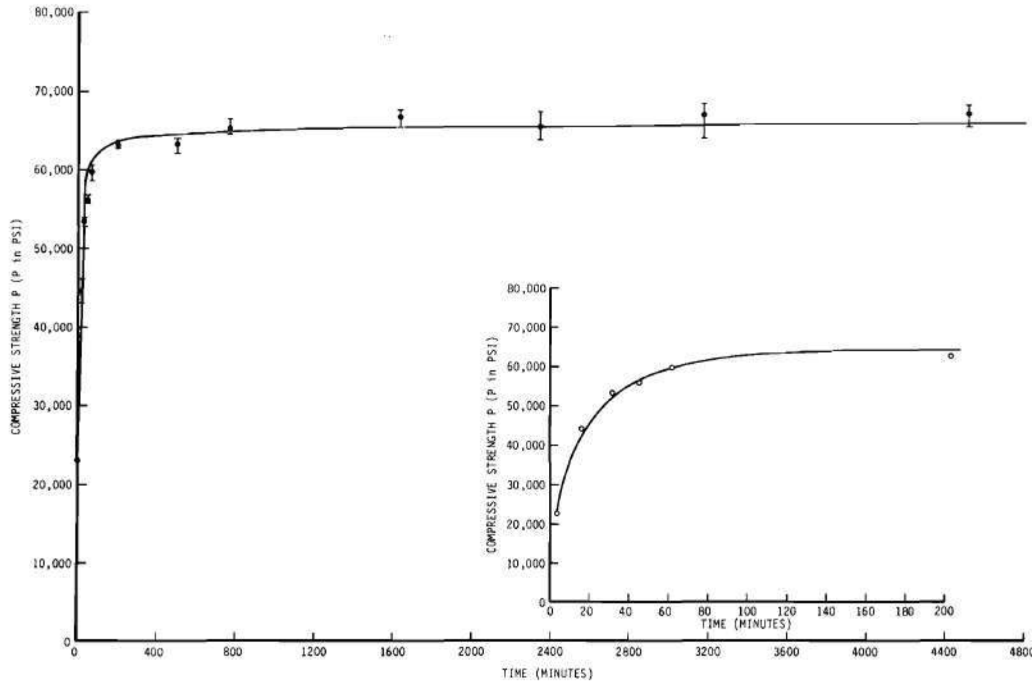

Figure B-5. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 58,800 psi for 1 Minute.

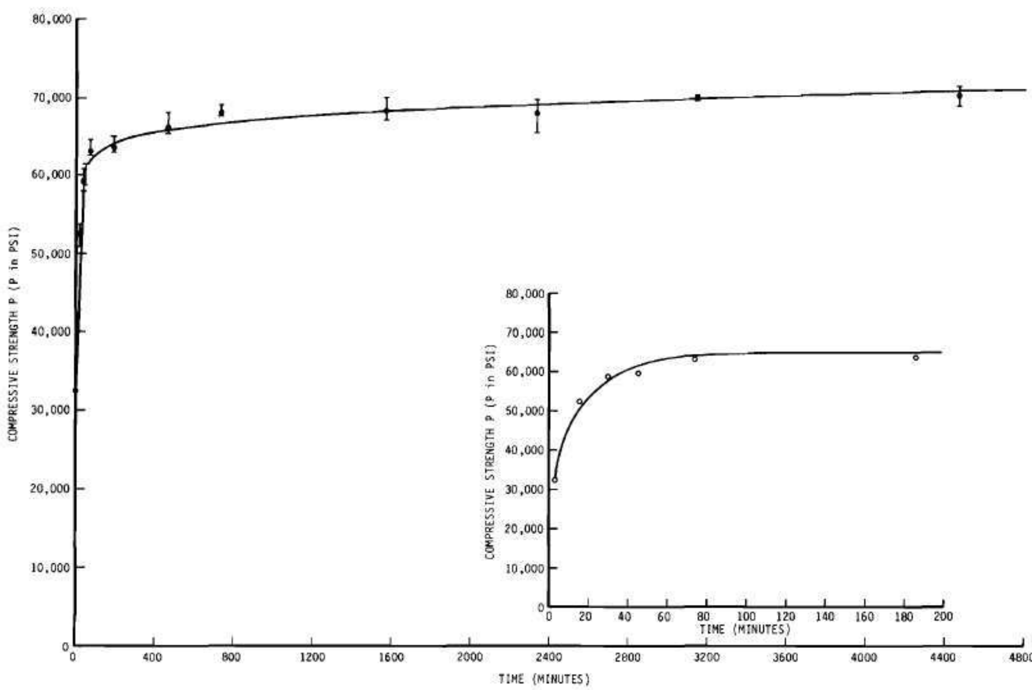

Figure B-6. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 1 Minute.

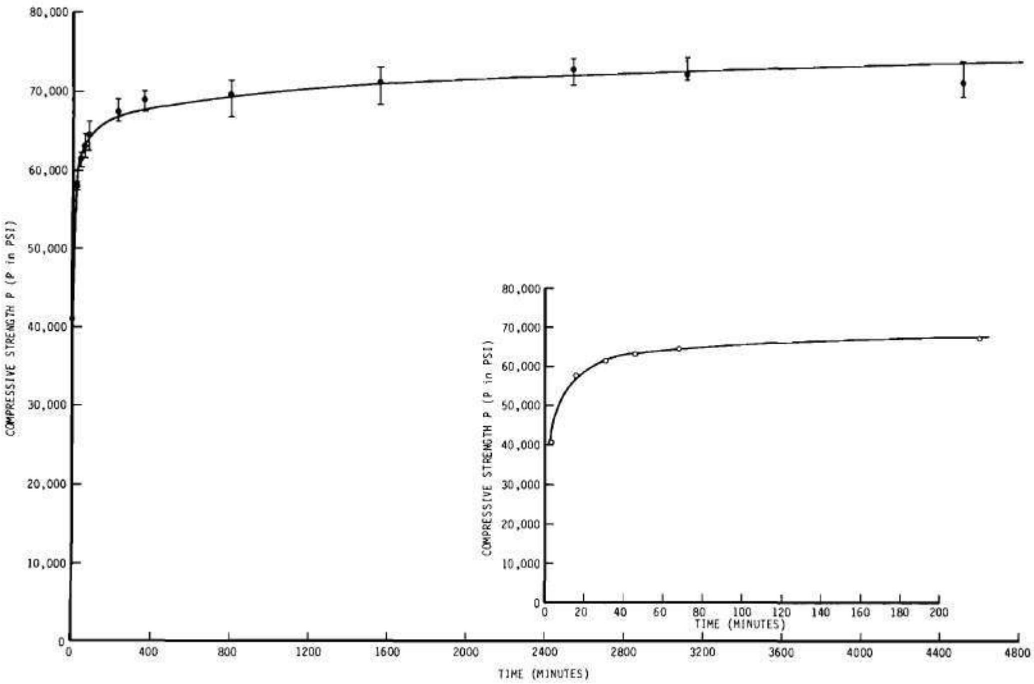

Figure B-7. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 98,000 psi for 1 Minute.

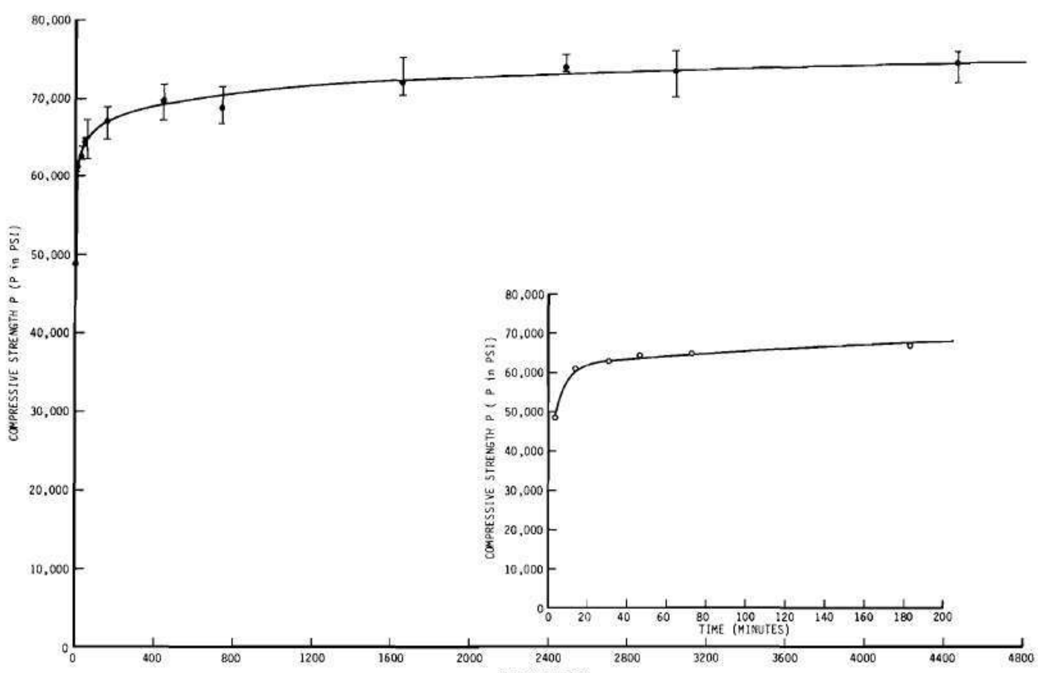

Figure B-8. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 117,600 psi for 1 Minute.

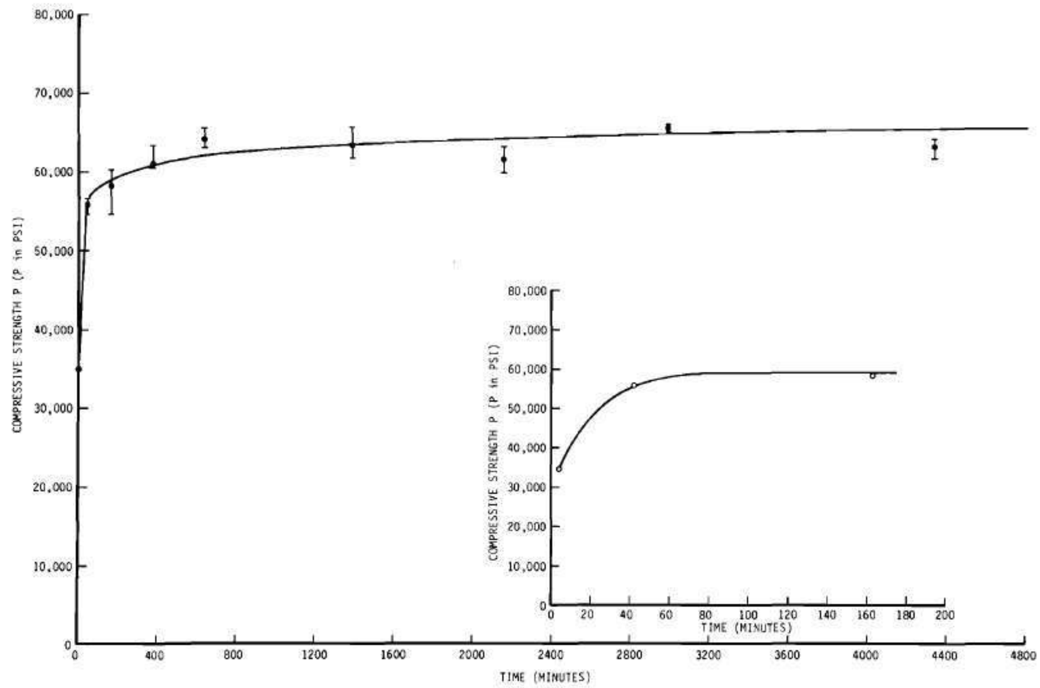

Figure B-9. Compressive Strength Versus Time for 40% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

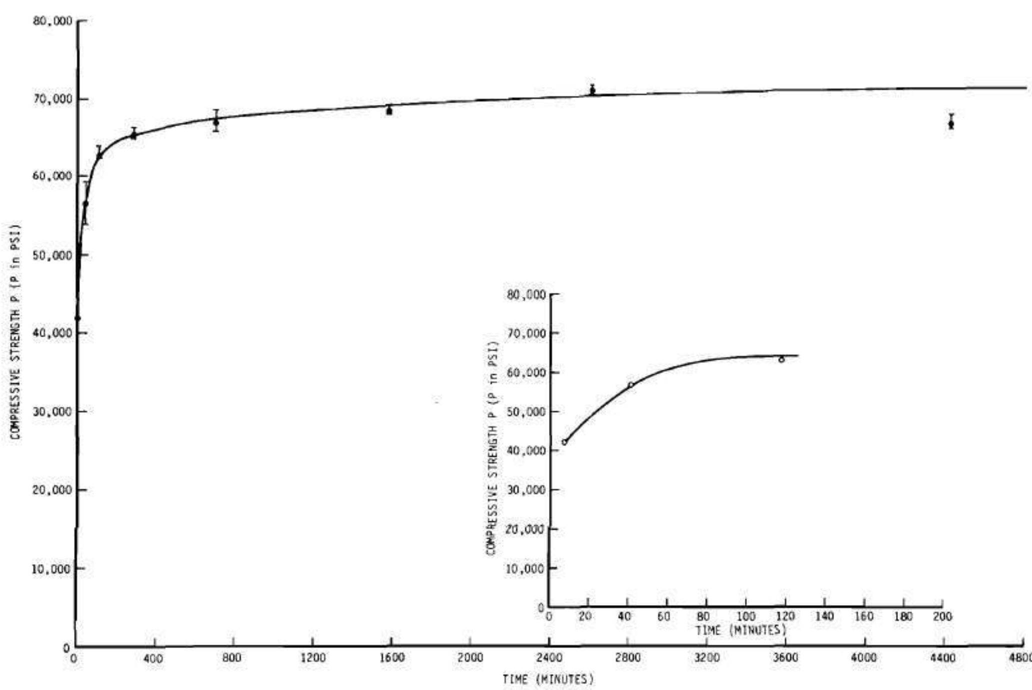

Figure B-10. Compressive Strength Versus Time for 50% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

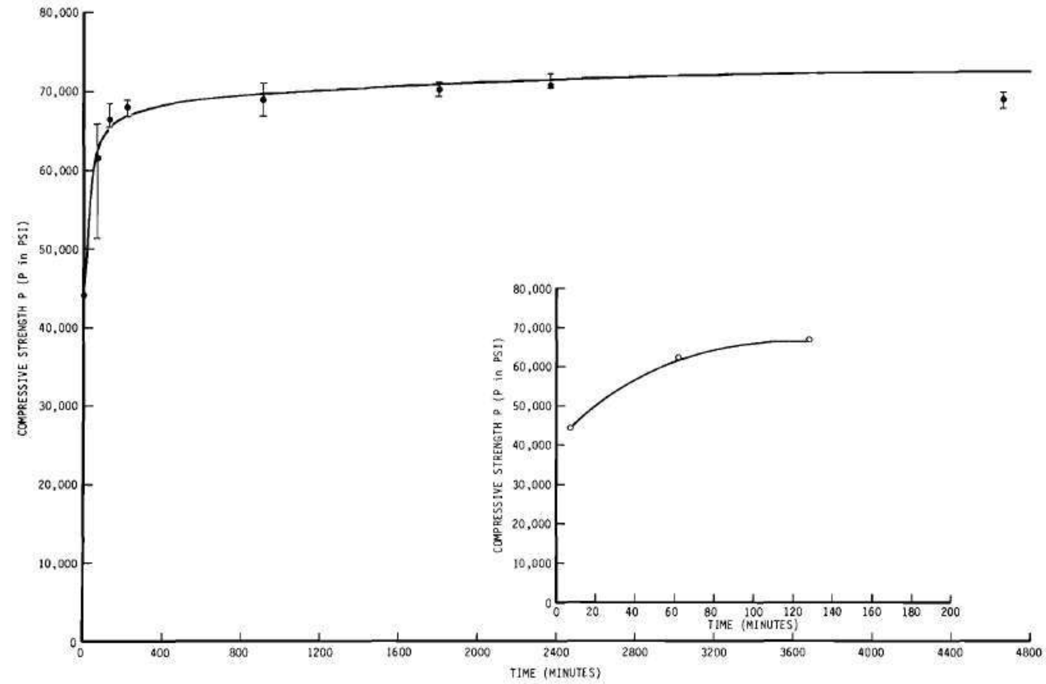

Figure B-11. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

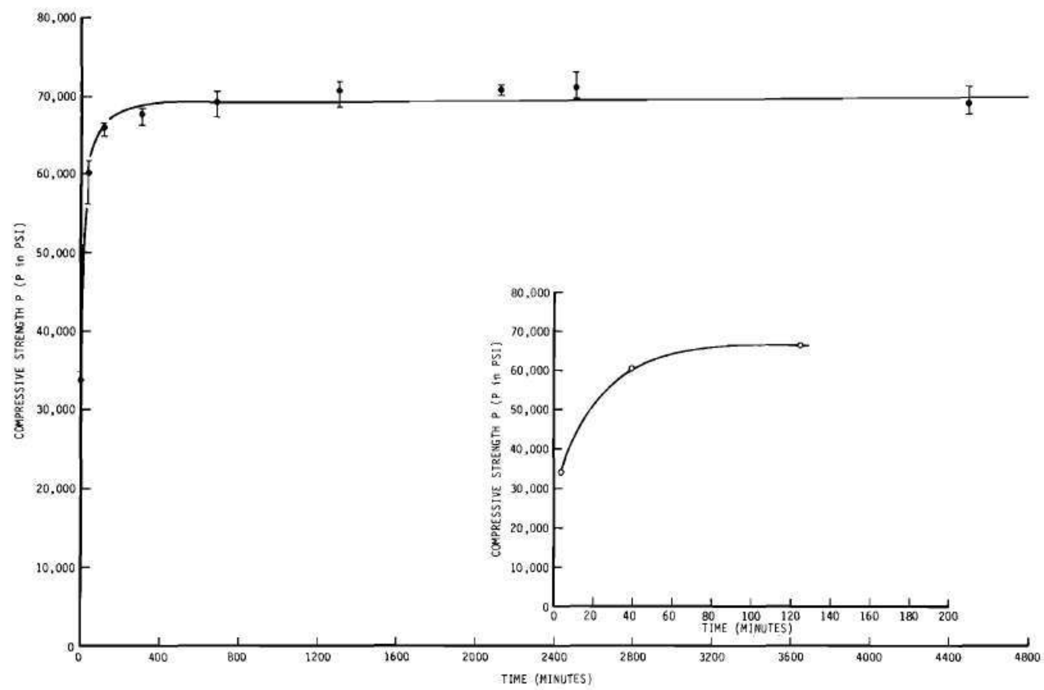

Figure B-12. Compressive Strength Versus Time for 70% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

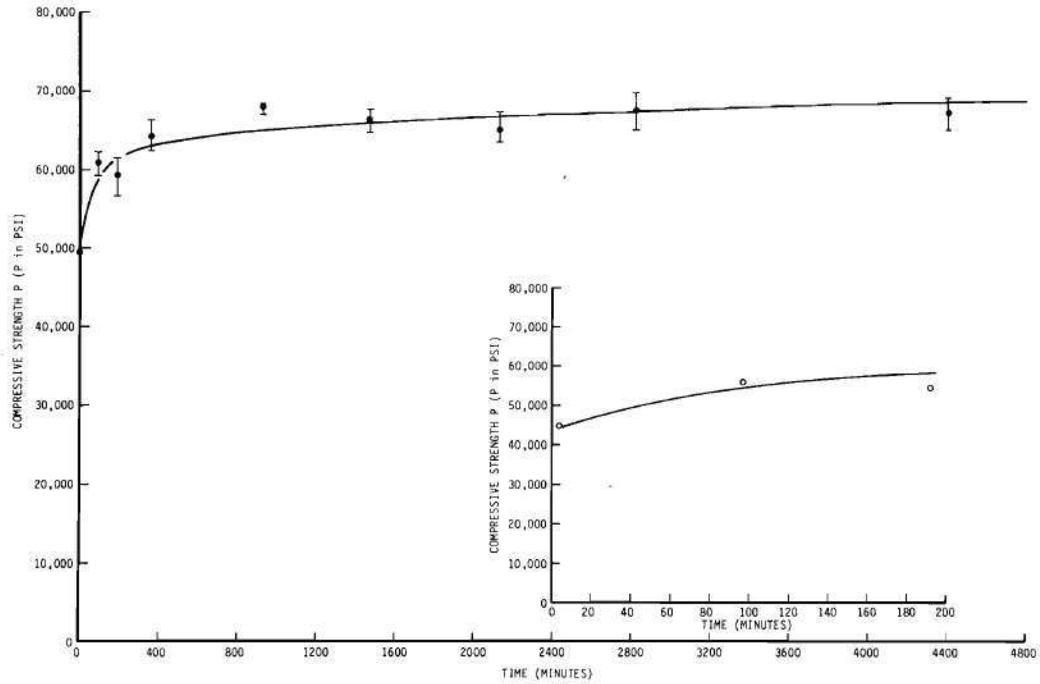

Figure B-13. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 5 Minutes.

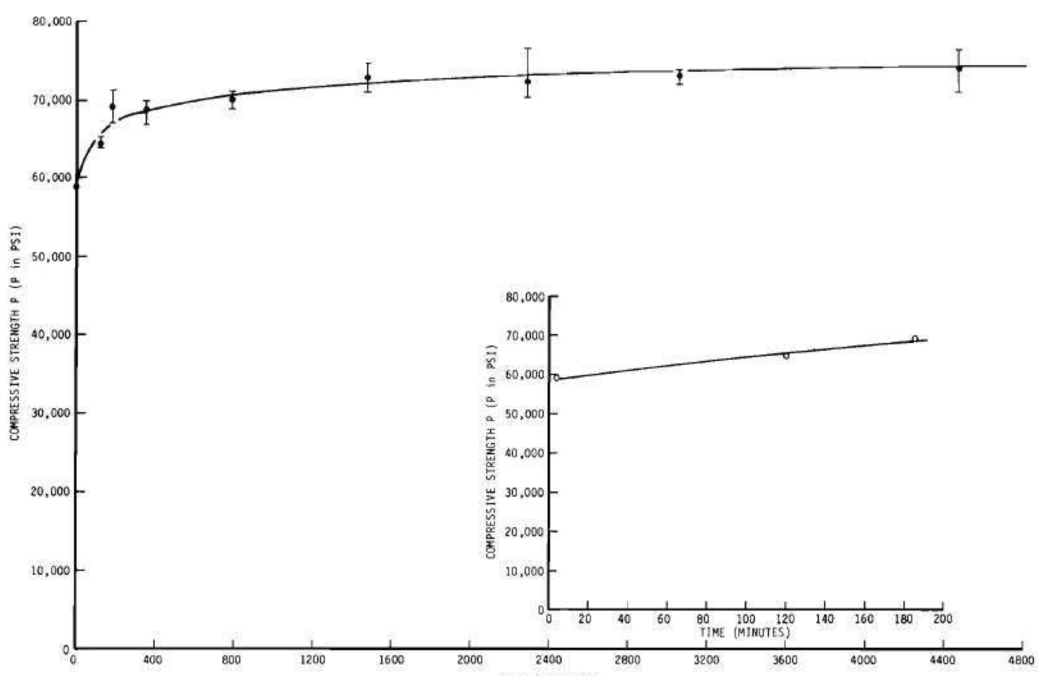

Figure B-14. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 10 Minutes.

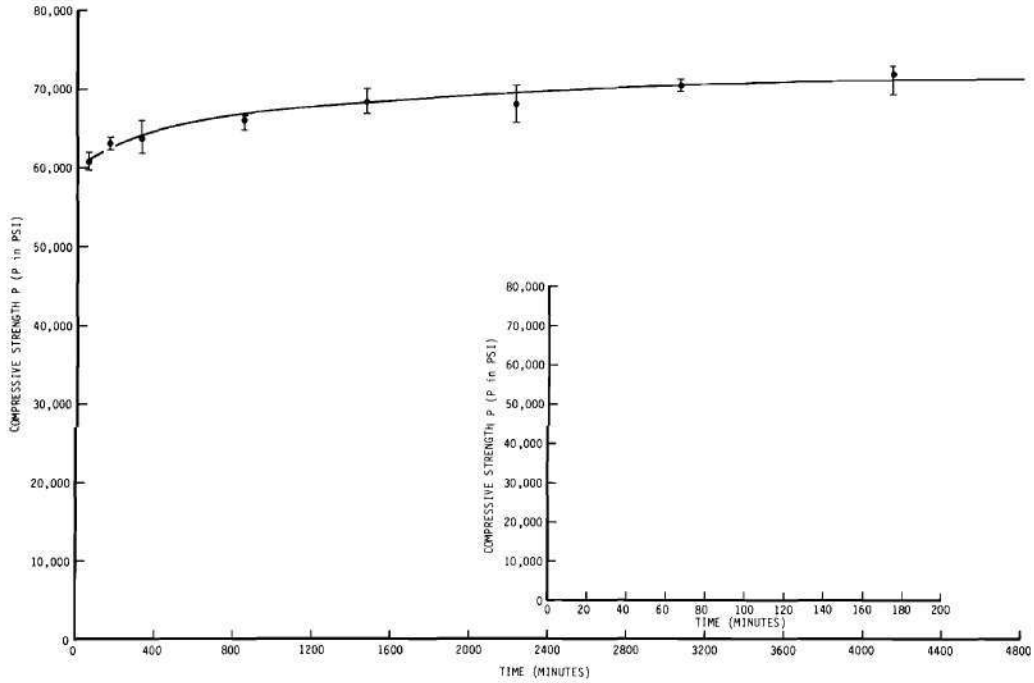

Figure B-15. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 1 Minute at 37°C.

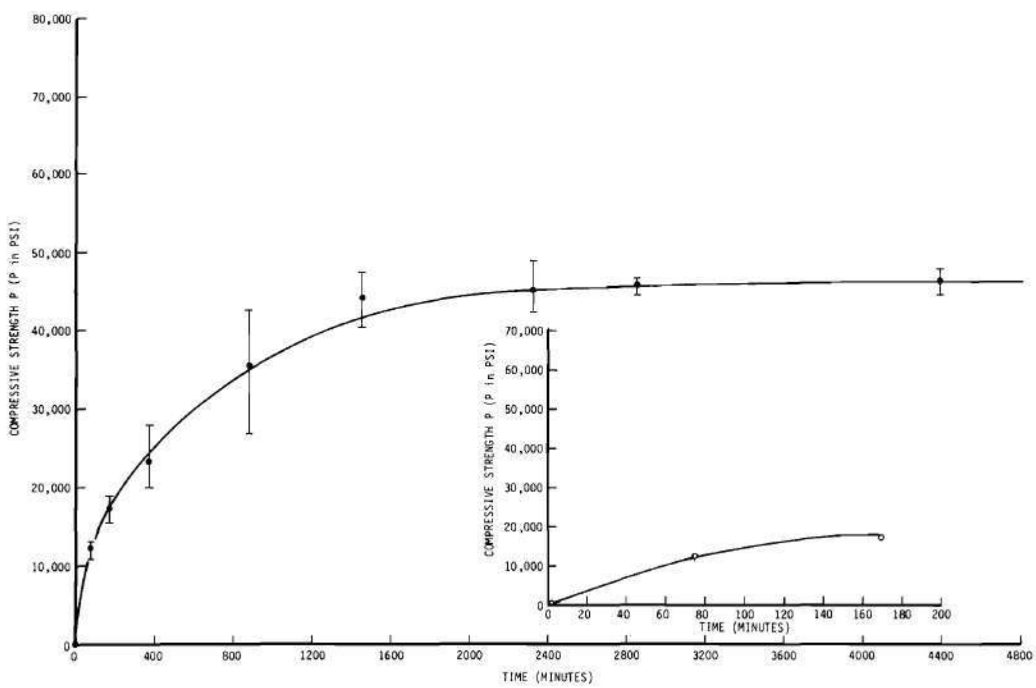

Figure B-16. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed by Hand at 550 psi for 1 Minute.

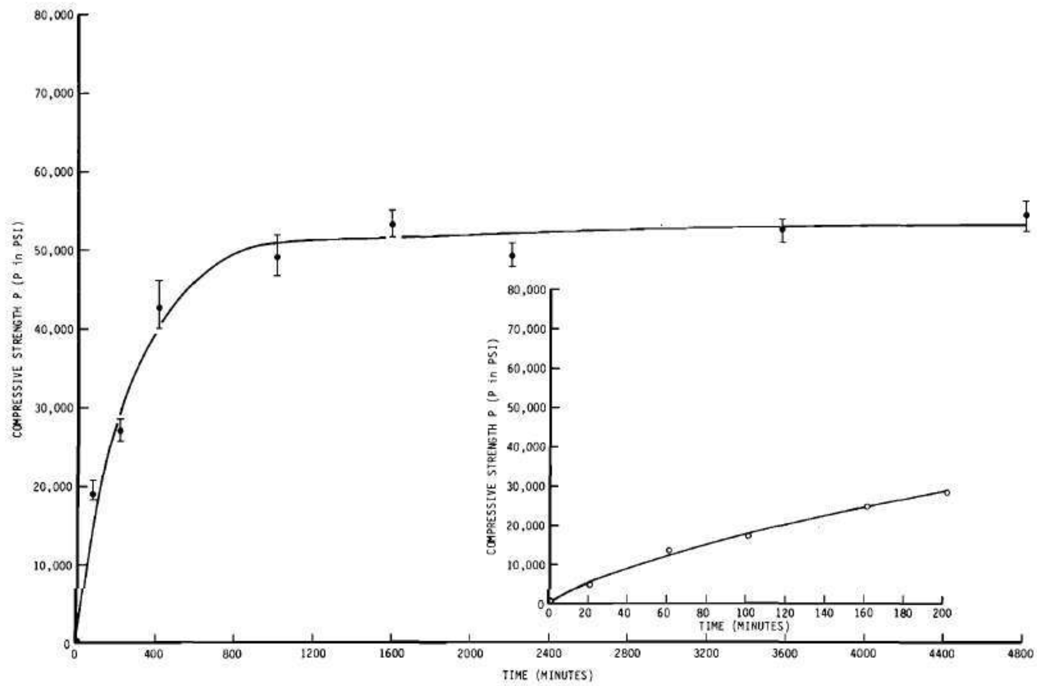

Figure B-17. Compressive Strength Versus Time for 58.8% Mercury Amalgam Condensed by Hand at 34,000 psi for 5 Minutes.

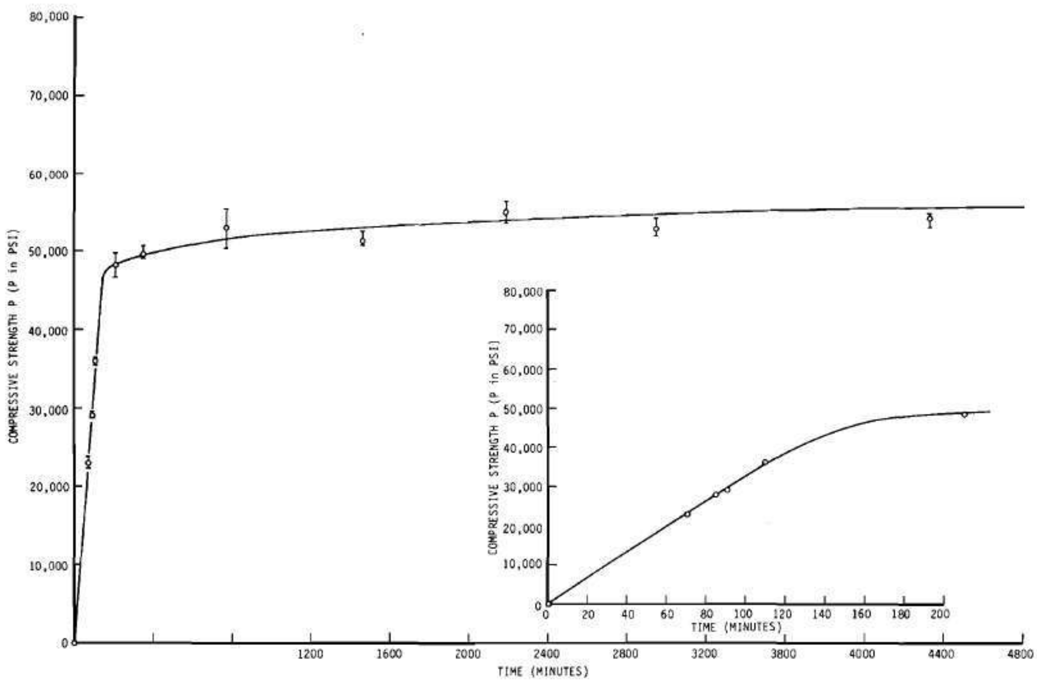

Figure B-18. Compressive Strength Versus Time for 58.8% Mercury Amalgam Ultrasonically Condensed with a Low Amplitude at Zero Pressure for 20 Seconds.

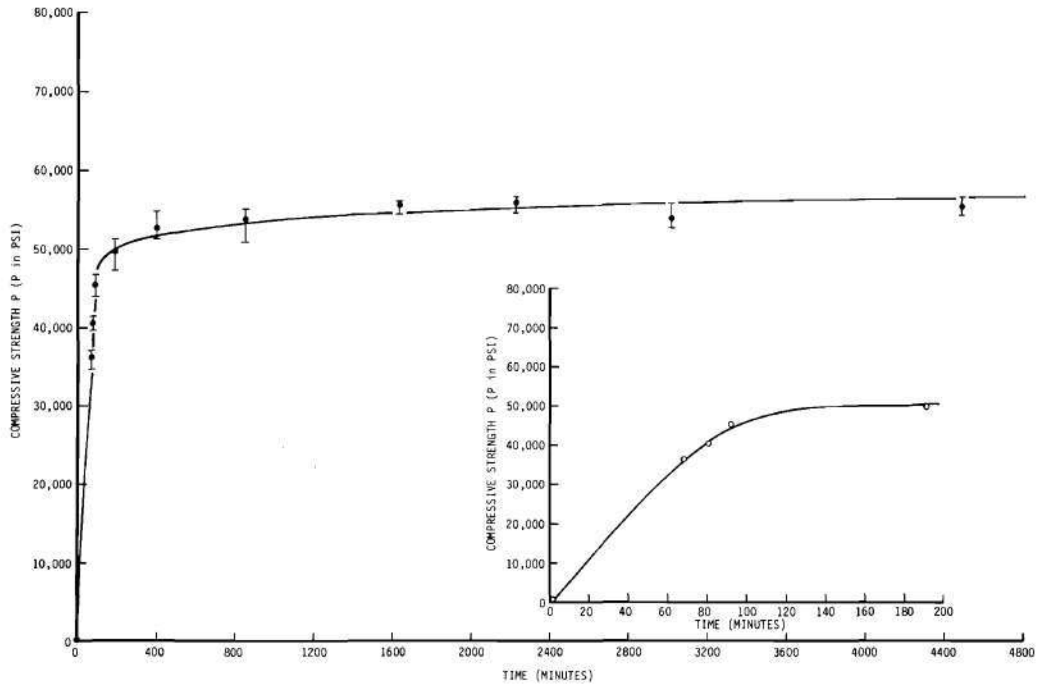

Figure B-19. Compressive Strength Versus Time for 58.8% Mercury Amalgam Ultrasonically Condensed with a High Amplitude at 9,800 psi for 10 Seconds.

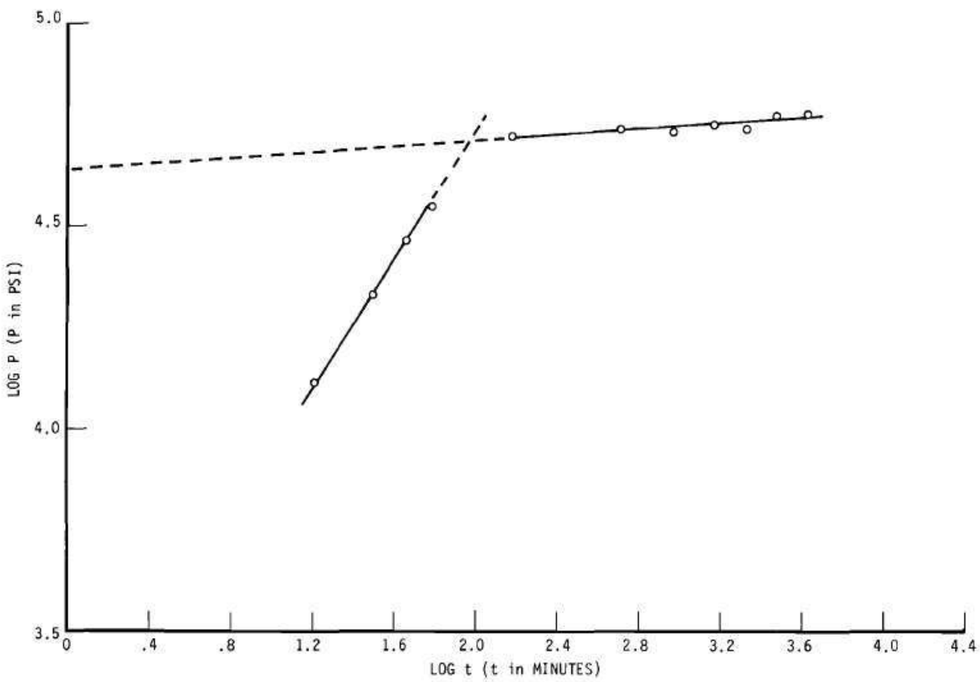

Figure B-20. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 9,800 psi for 1 Minute.

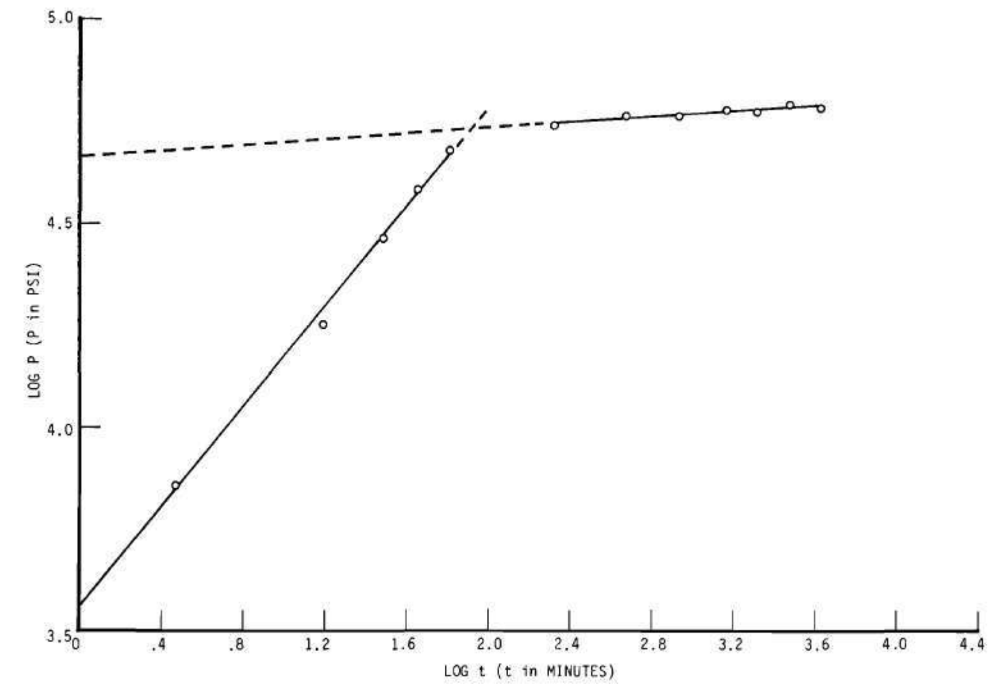

Figure B-21. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 19,600 psi for 1 Minute.

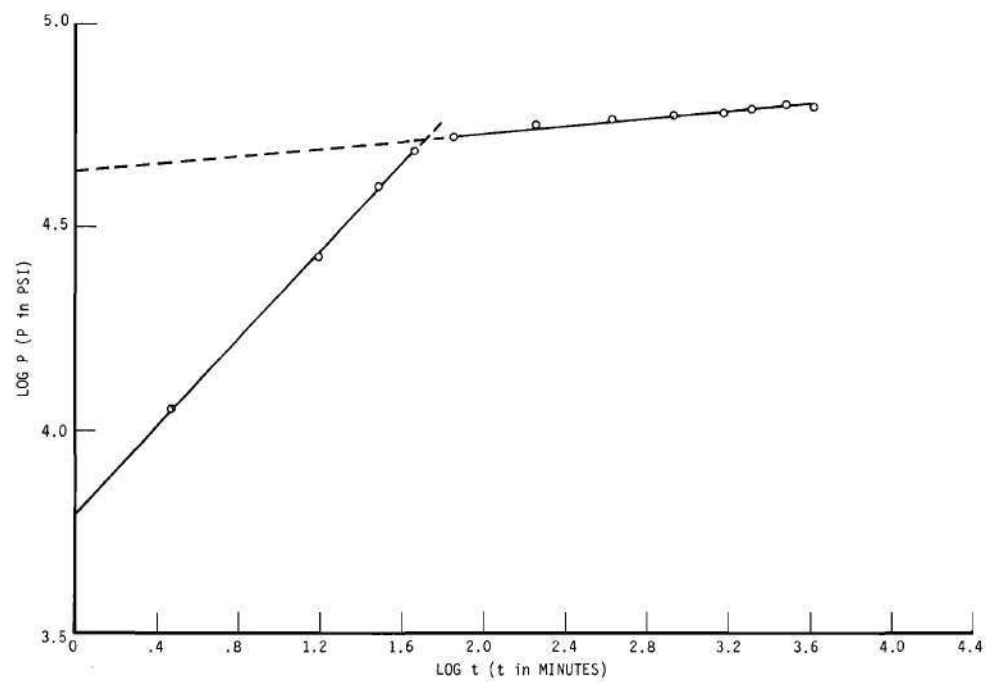

Figure B-22. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 29,400 psi for 1 Minute.

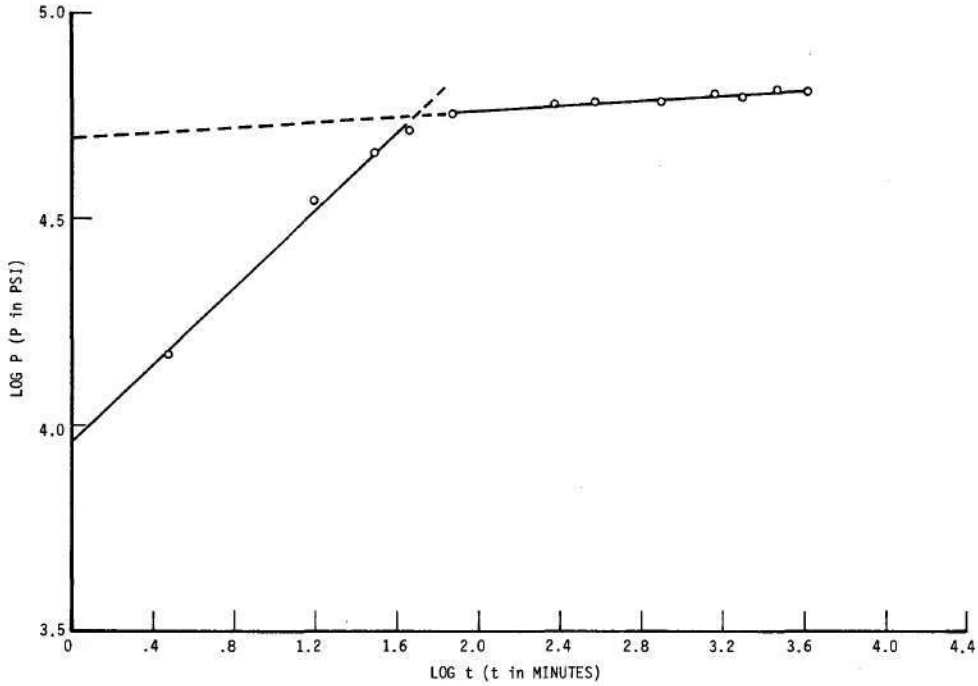

Figure B-23. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 39,200 psi for 1 Minute.

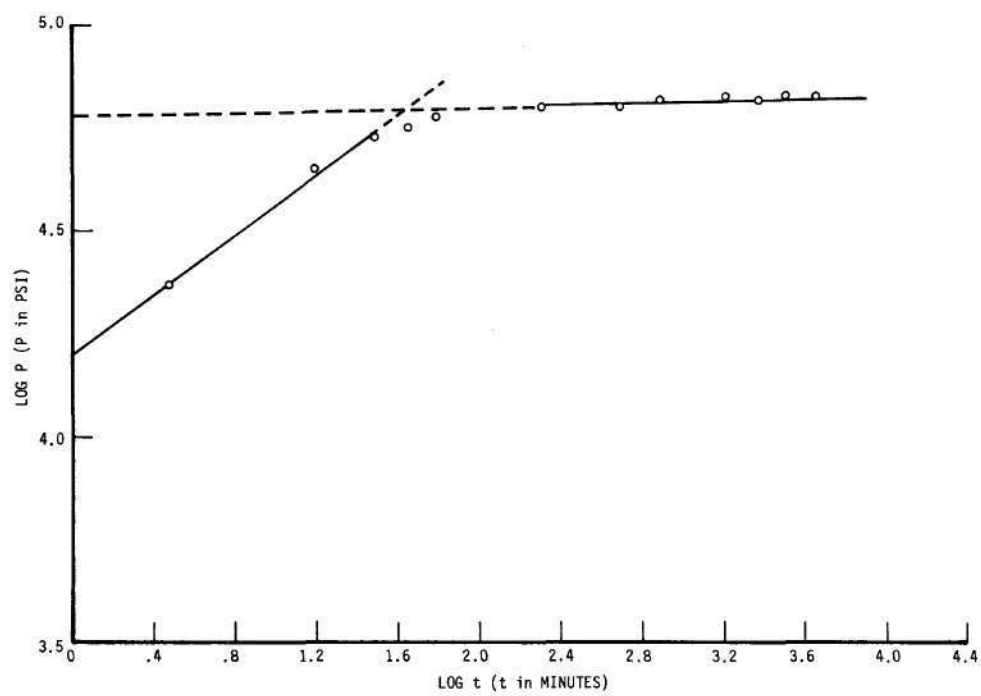

Figure B-24. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 58,800 psi for 1 Minute.

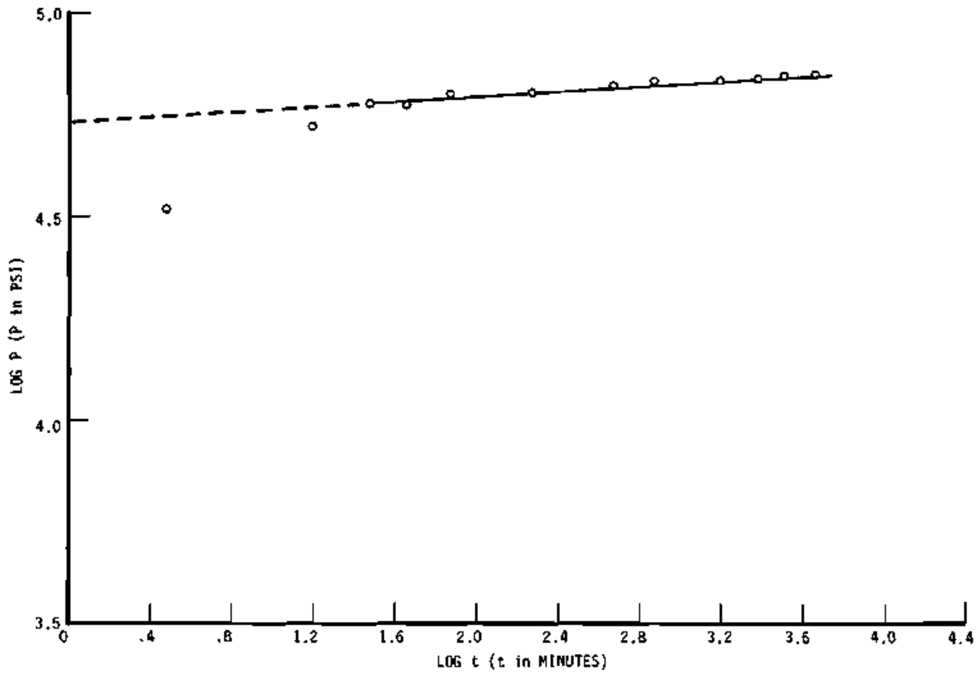

Figure B-25. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 1 Minute.

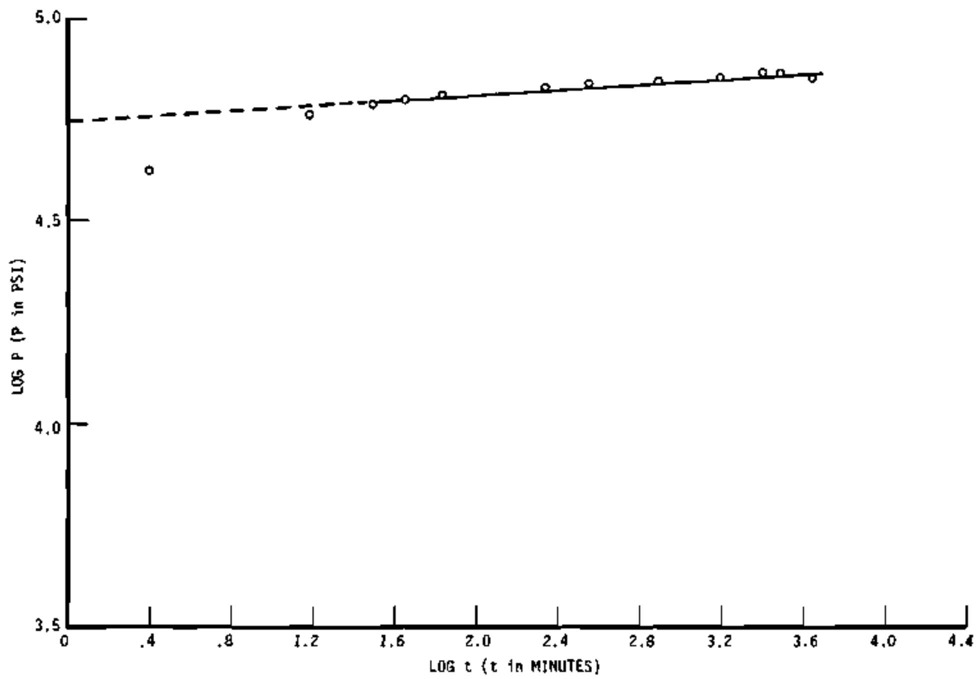

Figure B-26. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 98,000 psi for 1 Minute.

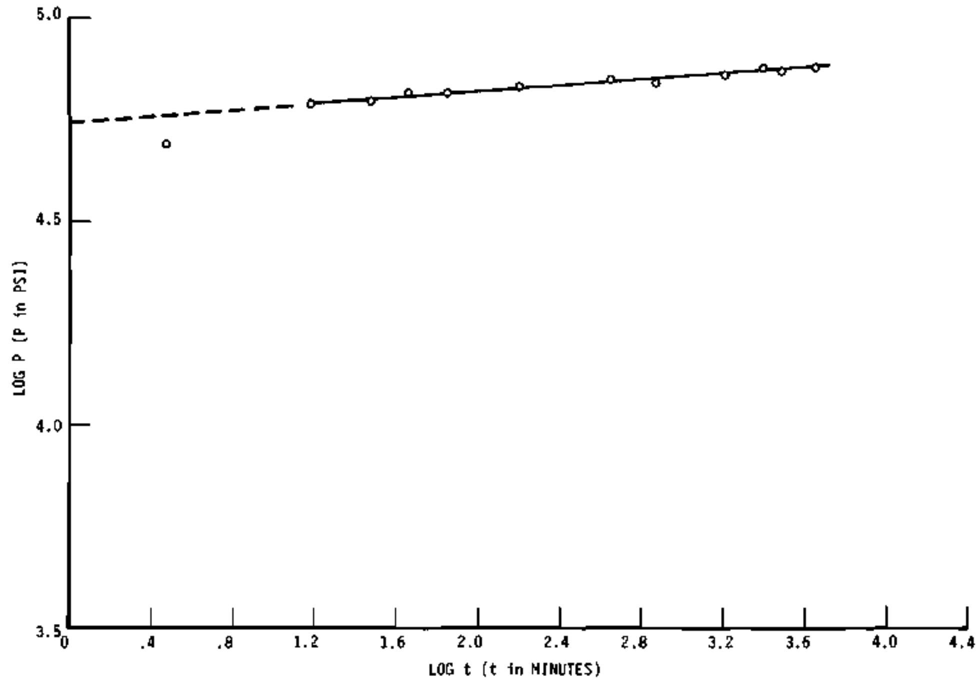

Figure B-27. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 117,600 psi for 1 Minute.

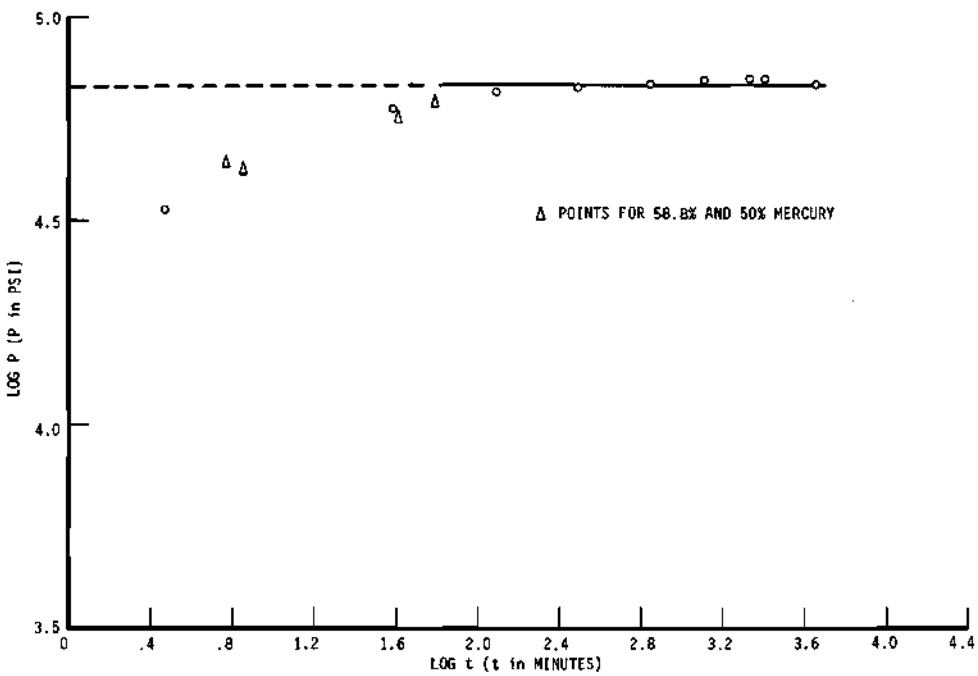

Figure B-28. Log Compressive Strength Versus Log Time for 70% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

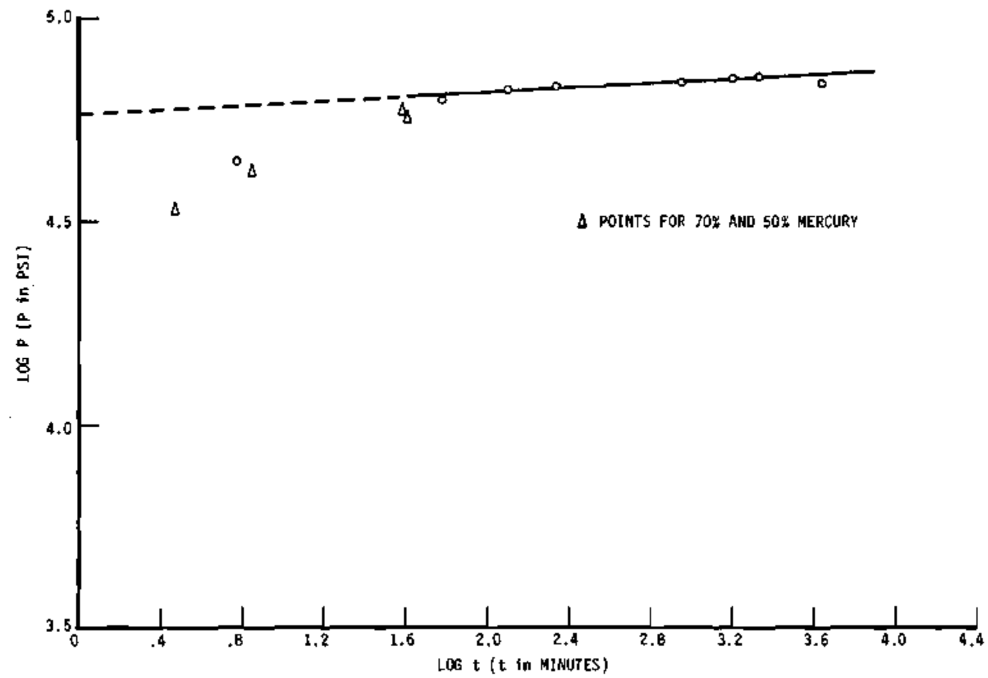

Figure B-29. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

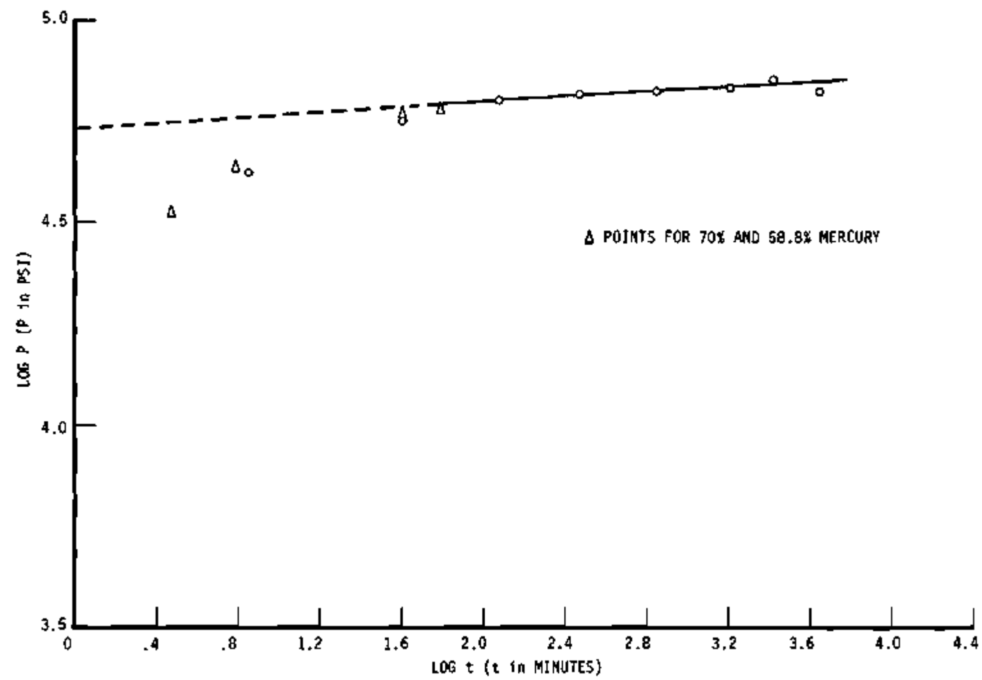

Figure B-30. Log Compressive Strength Versus Log Time for 50% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

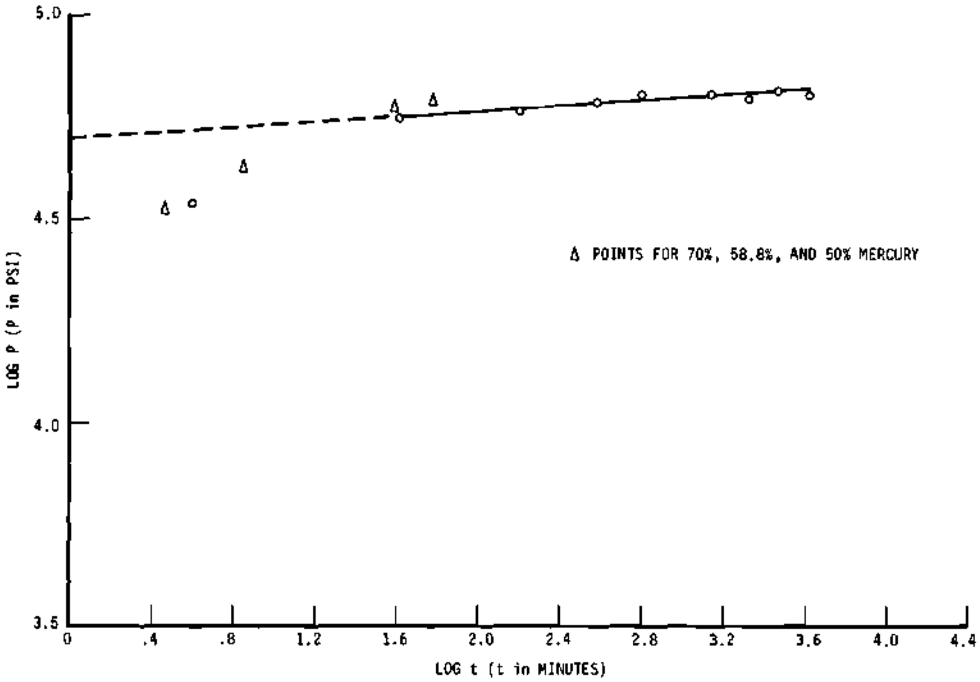

Figure B-31. Log Compressive Strength Versus Log Time for 40% Mercury Amalgam Condensed at 86,200 psi for 1 Minute.

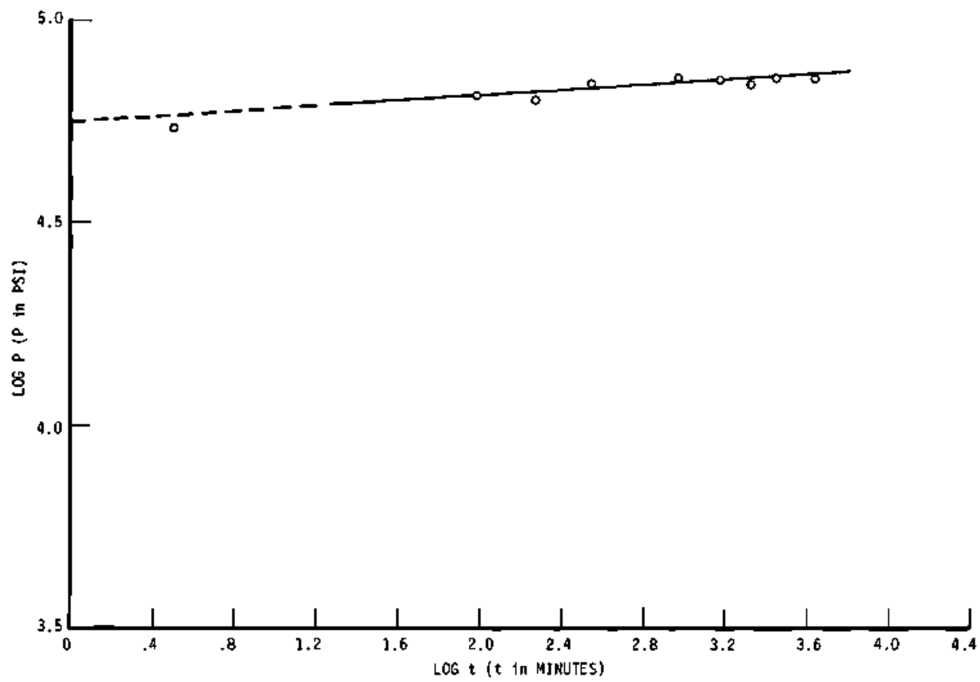

Figure B-32. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 5 Minutes.

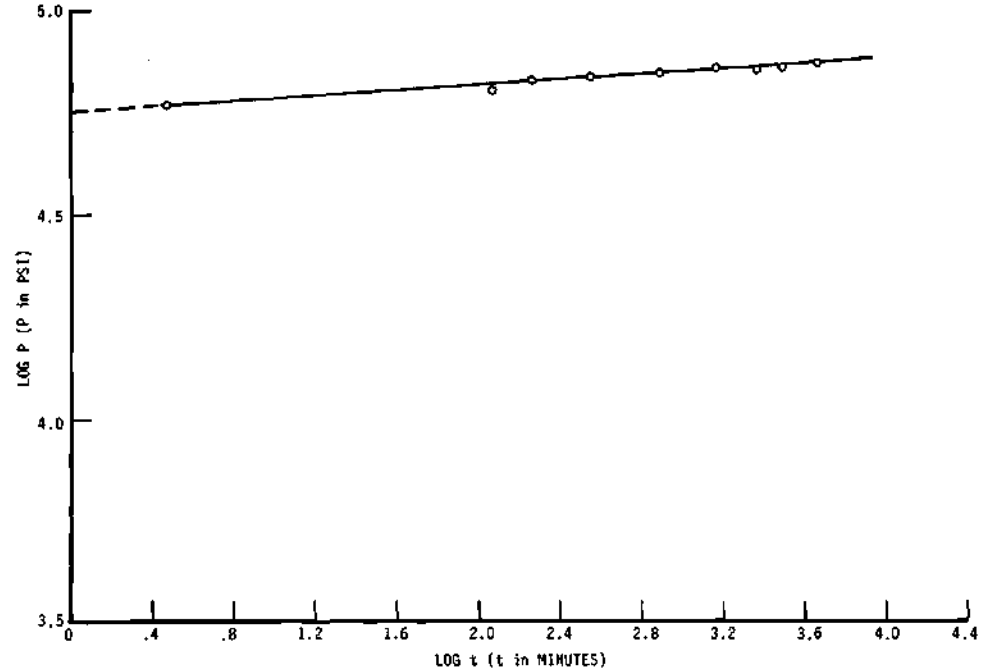

Figure B-33. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 10 Minutes.

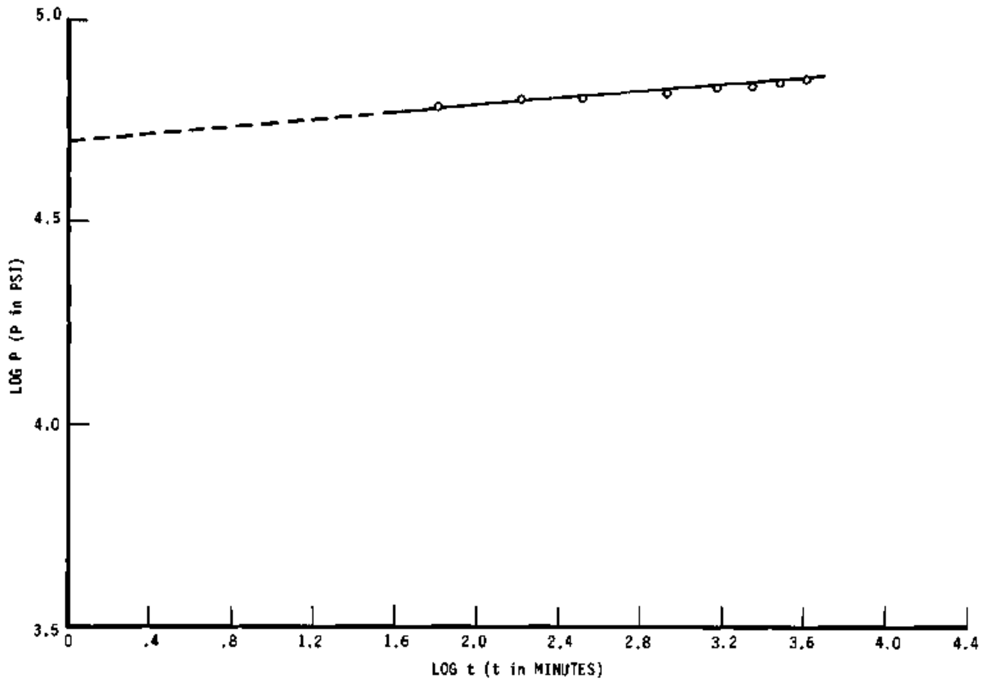

Figure B-34. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Condensed at 78,400 psi for 1 Minute at 37°C.

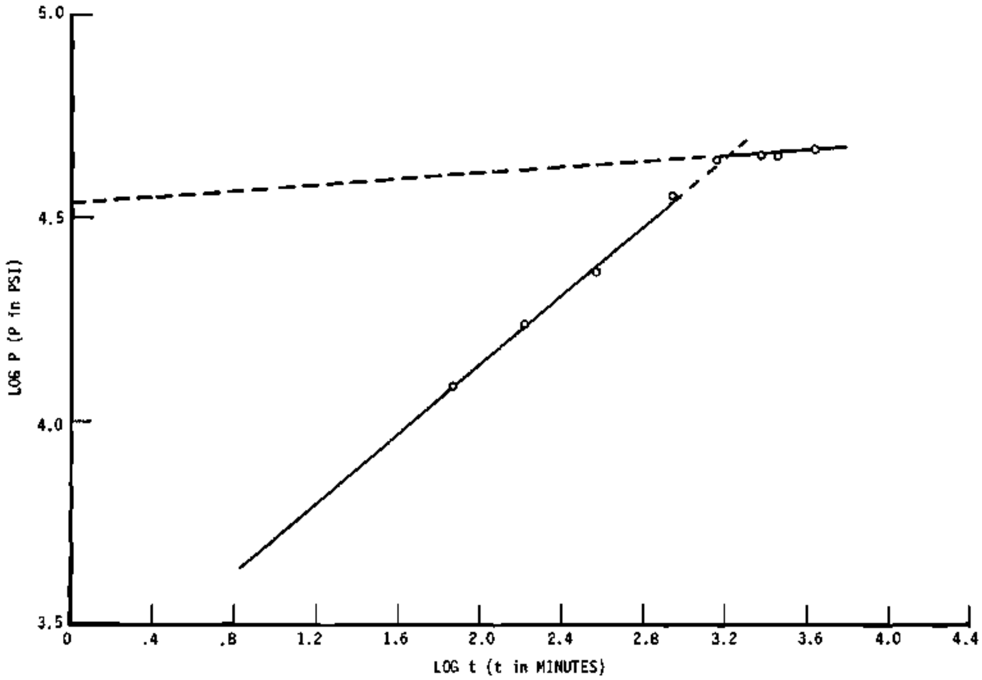

Figure B-35. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Hand Condensed at 550 psi for 1 Minute.

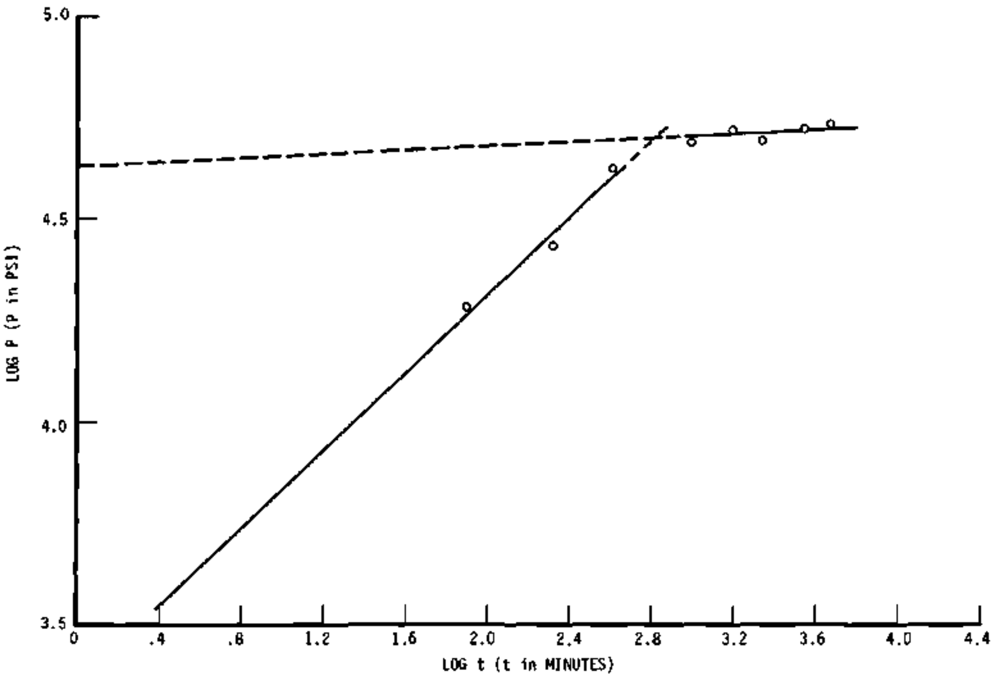

Figure B-36. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Hand Condensed at 34,000 psi for 1 Minute.

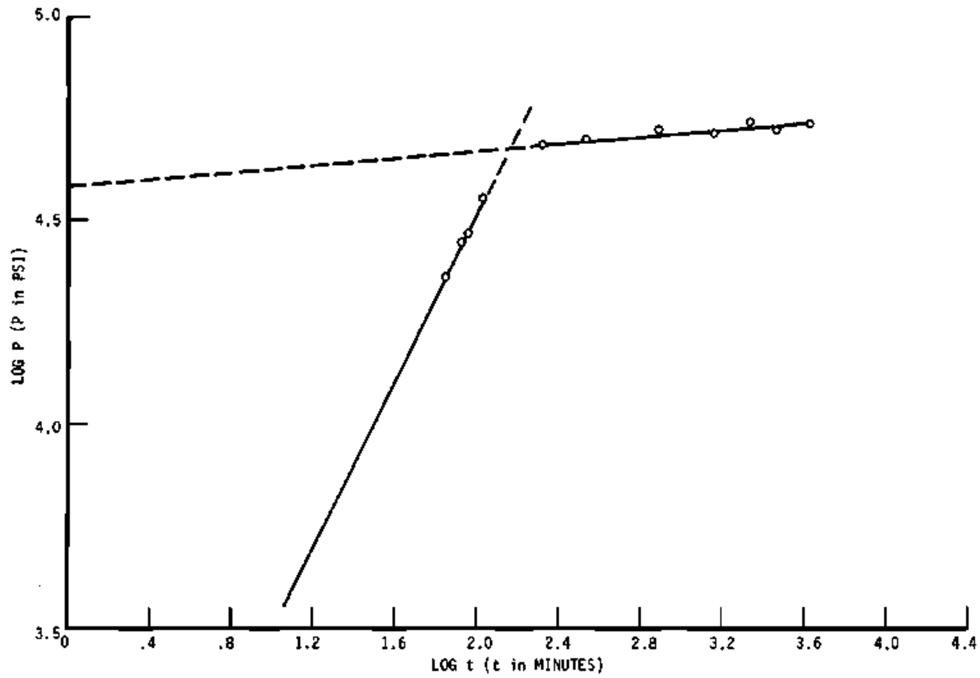

Figure B-37. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Ultrasonically Condensed with a Low Amplitude at Zero Pressure for 20 Seconds.

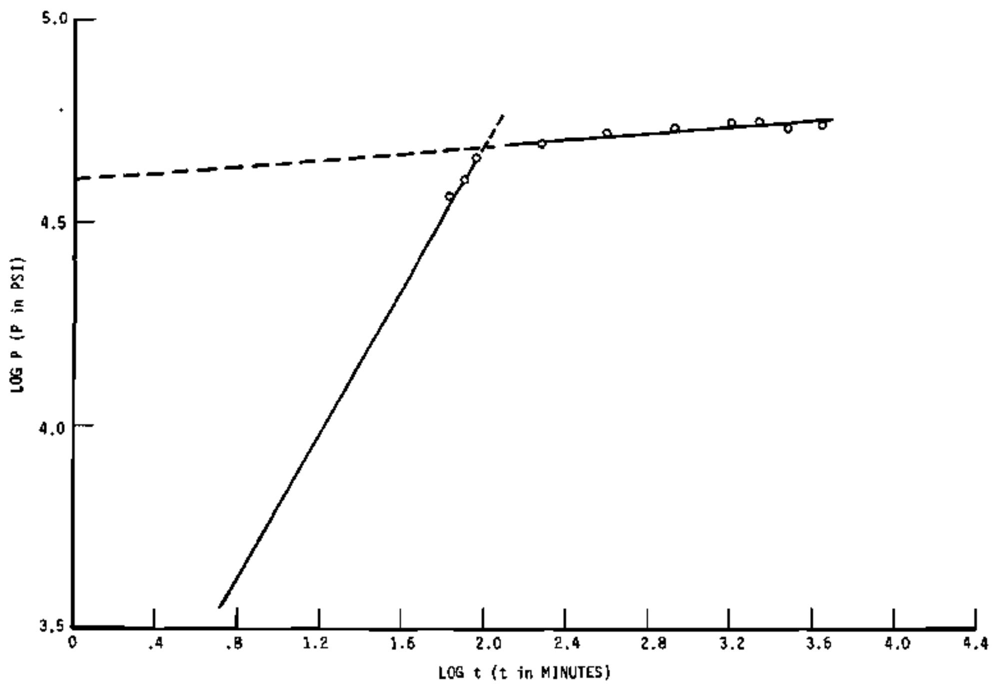

Figure B-38. Log Compressive Strength Versus Log Time for 58.8% Mercury Amalgam Ultrasonically Condensed with a High Amplitude at 9,800 psi for 10 Seconds.

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